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1 **Effect of stimulus type and motion on smooth pursuit in adults and**  
2 **children**

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39 **Abstract**

40 **Purpose:** This study presents a 2° customized animated stimulus developed to evaluate  
41 smooth pursuit in children and investigates the effect of its predetermined  
42 characteristics (stimulus type and size) in an adult population. Then, the animated  
43 stimulus is used to evaluate the impact of different pursuit motion paradigms in  
44 children.

45 **Methods:** To study the effect of animating a stimulus, eye movement recordings were  
46 obtained from 20 young adults while the customised animated stimulus and a standard  
47 dot stimulus were presented moving horizontally at a constant velocity. In order to  
48 study the effect of using a larger stimulus size, eye movement recordings were obtained  
49 from 10 young adults while presenting a standard dot stimulus of different size (1° and  
50 2°) moving horizontally at a constant velocity. Finally, eye movement recordings were  
51 obtained from 12 children while the 2° customized animated stimulus was presented  
52 following three different smooth pursuit motion paradigms. Performance parameters,  
53 including gains and number of saccades, were calculated for each stimulus condition.

54 **Results:** The animated stimulus produced in young adults significantly higher velocity  
55 gain (mean: 0.93; 95% CI: 0.90-0.96;  $p=0.014$ ), position gain (0.93; 0.85-1;  $p=0.025$ ),  
56 proportion of smooth pursuit (0.94; 0.91-0.96,  $p=0.002$ ) and fewer saccades (5.30; 3.64-  
57 6.96,  $p=0.008$ ) than a standard dot (velocity gain: 0.87; 0.82-0.92; position gain: 0.82;  
58 0.72-0.92; proportion smooth pursuit: 0.872; 0.83-0.90; number of saccades: 7.75;  
59 5.30-10.46). In contrast, changing the size of a standard dot stimulus from 1° to 2° did  
60 not have an effect on smooth pursuit in young adults ( $p>0.05$ ). Finally, smooth pursuit  
61 performance did not significantly differ in children for the different motion paradigms  
62 when using the animated stimulus ( $p>0.05$ ).

63 **Conclusions:** Attention-grabbing and more dynamic stimuli, such the developed  
64 animated stimulus might potentially be useful for eye movement research. Finally, with  
65 such stimuli, children perform equally well irrespective of the motion paradigm used.

66 **Keywords:** smooth pursuit, animated stimulus, children, pursuit performance, child-  
67 friendly

68

69 Exploration of the space around us ideally requires not only normal visual acuity but  
70 also the absence of any ocular pathology, including normal eye movements. In order  
71 to stabilise the retinal image, there are different types of eye movements that suit  
72 different types of objects, motions and conditions.<sup>1</sup> For instance, smooth pursuit  
73 involves conjugate eye movements responsible for smooth, accurate tracking of a  
74 slow moving object in order to maintain its image on the foveas,<sup>1</sup> whereas saccades  
75 are the eye movements responsible for shifts of gaze that bring the image of a  
76 peripherally placed object of interest into the foveal region.<sup>1</sup>

77 Saccades and smooth pursuit eye movements have been traditionally studied using dots  
78 and light spots in both adults<sup>2-4</sup> and children.<sup>3, 5-8</sup> In contrast, different stimuli, such as  
79 cartoon characters<sup>9</sup> or faces,<sup>10</sup> have been designed to study eye movements in infants.  
80 The wider variety of stimuli used for eye movement research in infants are intended to  
81 maintain infant's attention, the main reason being that there might be a relationship  
82 between attention and eye movements, such that higher attention engagement might  
83 improve eye movement performance.<sup>11, 12</sup> Interestingly, such approaches aimed at  
84 increasing/maintaining attention in infants have not been adopted as a standard for eye  
85 movement research, even though recent evidence has shown that the stimulus type and  
86 its features also have an impact on eye movement performance in non-infant  
87 populations.<sup>13</sup> For example, Irving et al. (2011) reported significantly higher saccadic  
88 peak velocities, shorter saccadic latencies, and more accurate saccades when using  
89 cartoon pictures as stimuli than when using standard dots. The difference in  
90 performance between the stimuli was evident and statistically significant in young  
91 children but decreased up to the age of 8-9 years, while in adults the differences were  
92 negligible.<sup>13</sup> Similar results were found by the same authors for smooth pursuit eye  
93 movements. For instance, in children the use of animal pictures as smooth pursuit

94 targets resulted in significantly higher gains compared to standard dots.<sup>13</sup> Although  
95 higher gains using cartoons were also observed in adults, the difference in performance  
96 between stimuli was not significant.<sup>13</sup> These results support the idea that eye  
97 movements can be assessed more successfully using more interesting and meaningful  
98 targets and heighten the need for more appropriate stimuli to investigate oculomotor  
99 control, especially in young populations.

100 Moreover, there is currently no standardised stimulus motion to study smooth pursuit  
101 eye movements, resulting in three main motion paradigms having been used in pursuit  
102 studies: the ramp, the step-ramp, and the sinusoidal. The ramp is probably the simplest  
103 approach, using a target that starts moving suddenly at a constant velocity for a certain  
104 period of time.<sup>14</sup> At the onset of the target movement, the smooth pursuit performance  
105 is poor and often begins with an initial saccade, but then there is a notable increase in  
106 eye velocity that leads to an improvement in the smooth pursuit response.<sup>14</sup> To avoid  
107 or minimize the effect of this initial saccade, some authors have modified the stimulus  
108 motion and developed what is known as the step-ramp paradigm. In this approach, the  
109 fixation target suddenly moves (step) prior to the constant velocity (ramp) movement  
110 of the target,<sup>14</sup> in order to 'alert' the subject to the onset of motion. Eye movements can  
111 also be studied in response to a stimulus for which velocity continuously changes in a  
112 sinusoidal manner. While multiple studies evaluating the effect of age on smooth  
113 pursuit in adults have used stimuli moving at constant velocity,<sup>15-17</sup> studies in children  
114 and infants have used not only different constant velocity motions<sup>8, 18</sup> but also  
115 sinusoidal motion paradigms.<sup>6, 7, 19</sup> Moreover, the literature suggests that there is an  
116 issue with the choice of smooth pursuit motion paradigm in infant and child  
117 populations, which does not persist in adult populations. For instance, an early study  
118 suggested that the step-ramp should be used in young infants to increase their

119 attention.<sup>20</sup> The rationale discussed by the author was that the saccade prior to the  
120 movement of the target may be more effective in increasing infants' awareness and  
121 attention than other stimulus motions. In contrast, sinusoidal motions have been  
122 described as a better option for school age children.<sup>6, 20</sup> Interestingly, we are not aware  
123 of any published study assessing smooth pursuit differences in young populations  
124 between these motion paradigms.

125 This study aimed to evaluate any possible advantage of using an animated stimulus  
126 developed for eye movement studies in children and investigate the effect of the  
127 predetermined characteristics of such stimulus (type and size) in young adults. Finally,  
128 this animated stimulus was used in a study of pursuit in a small group of children to  
129 investigate the effect of motion paradigm on smooth pursuit performance in young  
130 populations.

## 131 **Materials and Methods**

### 132 **Participants**

133 Twenty young adults (mean age  $24 \pm SD 1.42$ ; range: 21 to 27) predominantly males  
134 (13/20) were recruited for experiment 1, and ten young adults (mean age of  $21.50 \pm SD$   
135  $2.12$ ; range: 20 to 25) with no difference in gender distribution (5/10) were recruited  
136 for experiment 2. Twelve child participants (mean age  $6.33 \pm SD 3.31$ ; range 3 to 14),  
137 predominantly males (7/12) were recruited for experiment 3. The adult subjects were  
138 students and staff at the School of Optometry and Vision Sciences at Cardiff University,  
139 and the child subjects were recruited through local advertising.

140 All three experiments received ethical approval from the Cardiff University School of  
141 Optometry and Vision Sciences Research and Audit Ethics Committee, and procedures  
142 were in accordance with the guidelines of the Declaration of Helsinki. Written consent

143 forms were obtained from the young adult participants and consent forms were received  
144 from both the children and their parents or legal guardians. All participants were  
145 screened to confirm visual acuity of at least logMAR 0.1 and the absence of strabismus.  
146 The tests comprised near and distance visual acuity with current prescription, if any,  
147 and eye alignment by cover test. The visual acuity criteria were set to include  
148 participants with low uncorrected refractive errors, mainly myopia.

### 149 **Visual stimulus and setup**

150 The newly developed animated stimulus comprised an animal cartoon image that  
151 moved horizontally, while continuously changing shape and colour as it morphed into  
152 different animals (Figure 1 and Video 1, Supplemental Digital Content 1, Video that  
153 shows the eye movement recording of a 4 year old child using our customised setup  
154 and animated stimulus). The perception of a more complex image such as a face, can  
155 be influenced by the size of that image,<sup>21</sup> such that larger angular size may improve  
156 recognition and performance, especially in young populations. In addition, eye  
157 movements such as saccades are not dependent on stimulus size up to  
158 sizes of 3-5°. <sup>22, 23</sup> For these reasons, the size chosen for the customised animated  
159 stimulus was 2°, in order to maximise attention and to ensure that the size of the stimuli  
160 was the minimum necessary to allow the discrimination of the animal cartoon features.  
161 The animal's eyes and a small dot situated in the centre of the cartoon were maintained  
162 constant in order to provide a fixation point throughout the test.

163 The unchanging visual stimulus, referred to as a "*standard dot*" was a black filled circle  
164 containing a small white dot in the centre, which provided a fixation point. This  
165 standard visual stimulus was consistent with that used in previous studies.<sup>5, 6, 8, 13, 24</sup>  
166 Both visual stimuli were displayed on a computer monitor on a white background.



167 **Procedure and eye movement recordings**

168 *Eye Tracker*

169 Simultaneous eye movement recordings were performed using the Tobii TX300 (Tobii  
170 Technology, Stockholm, Sweden) eye tracker. The system comprises an eye tracker  
171 unit and a removable 23" widescreen monitor with 1920x1080 pixel resolution and an  
172 integrated webcam. This remote eye tracker uses the different Purkinje reflections of  
173 the eye to establish the horizontal and vertical position of both eyes at a sample rate of  
174 300Hz, and with a maximum gaze angle of  $\pm 35^\circ$ . The system gaze accuracy given by  
175 the manufacturer is  $\pm 0.5^\circ$  for monocular and  $\pm 0.4^\circ$  for binocular conditions.<sup>25</sup>

176 The participants' eye movements were recorded using Tobii Studio™ (Tobii  
177 Technology, Stockholm, Sweden) while displaying the stimuli on the monitor situated  
178 immediately above the eye tracker unit. Participants' performance and behaviour were  
179 recorded and also monitored live via the widescreen monitor integrated webcam.

180 *Calibration*

181 The position and height of the participant's chair and/or the eye tracker desk were  
182 adjusted to ensure that the subject's eyes were positioned 65cm away from the eye  
183 tracker and in front of the geometrical centre of the screen monitor. Prior to eye  
184 movement recording, the eye tracker was successfully calibrated for each participant at  
185 5 target positions on the monitor using the standard Tobii five point calibration. All  
186 stimuli presented later were contained within the calibrated area.

187 *Experiment 1: Effect of stimulus type on smooth pursuit performance in young adults*

188 The customised animated stimulus (Figure 1 and Video 1, Supplemental Digital  
189 Content 1) moved horizontally following a  $6^\circ/\text{sec}$  ramp paradigm. The stimulus  
190 appeared for one second at  $10^\circ$  to the left of the participant's straight ahead position.

191 After this initial fixation period, the stimulus moved horizontally (left to right)  
192 following a constant velocity motion (6°/sec) that lasted 3.33 seconds. The stimulus  
193 stopped when it was at 10° to the right of the participant's straight ahead position  
194 (Figure 2). Fixation periods were presented for two seconds between each ramp (left to  
195 right or right to left) before the stimulus moved again to the left or to the right. A total  
196 of four smooth pursuit ramps were presented, so that the stimulus moved left to right  
197 and right to left twice. The stimulus presentation lasted for 22.33 seconds. Then, the  
198 stimulus was changed to a standard dot subtending 1° and measures were repeated  
199 following the same motion paradigm and velocity. The authors chose to present the  
200 animated stimulus first so that the participants did not have previous experience with  
201 the smooth pursuit task, and therefore any learning effects were avoided when  
202 presenting this stimulus.

### 203 *Experiment 2: Effect of stimulus size on smooth pursuit performance in young adults*

204 In order to evaluate the effect of using a larger stimulus size on smooth pursuit  
205 performance, a standard dot stimulus was presented in two different sizes: subtending  
206 1° and 2° of visual angle. The presentation order of the two stimuli was alternated  
207 between participants. The stimuli followed the same motion and velocity as  
208 experiment 1.

### 209 *Experiment 3: Effect of stimulus motion paradigm on smooth pursuit performance in* 210 *children*

211 In this last experiment, the 2° customised animated stimulus was presented to study eye  
212 movements in a small group of children.

213 Because children are more likely to move during the eye movement recording than  
214 adults, a customised child-friendly head stabiliser was developed. This consisted of an

215 articulated arm with a forehead rest attached to the end (Figure 3). The forehead rest  
216 featured an adjustable plastic toy crown. The head stabiliser allowed participants to  
217 make slight head movements laterally and maintained their head at the optimal distance  
218 of 65cm from the monitor and eye tracker throughout the test. This customised head  
219 stabiliser naturally encouraged child participants to keep a steady position as large  
220 movements resulted in the crown falling off their head (Video 1, Supplemental Digital  
221 Content 1). This customised head stabiliser was aimed at maintaining the participants'  
222 distance from the eye tracker, and therefore maintaining the relative velocity of the  
223 smooth pursuit stimulus constant throughout the experiments and across subjects.

224 The same calibration and recording procedures were followed, but two additional  
225 motion paradigms were also presented using the animated stimulus. After the standard  
226 five point calibration was performed, the stimulus was presented following three  
227 different motion paradigms in the same order: a 6°/sec ramp, a 6°/sec step-ramp and a  
228 sinusoidal motion paradigm (peak velocity 6°/sec). The ramp motion paradigm,  
229 presented was identical to that used in experiments 1 and 2. In the step-ramp paradigm,  
230 the stimulus initially appeared at its starting position for one second, and then the  
231 stimulus was displaced 1° horizontally where it remained for another second before  
232 returning to the previous position to start the constant velocity ramp at 6°/sec. The target  
233 displacement (step) was repeated before the next ramp started. This smooth pursuit task  
234 lasted 23.33 seconds. For the sinusoidal motion, the fixation periods between ramps  
235 were deleted and the velocity of the stimulus changed continuously following a  
236 sinusoidal waveform. The duration for that task was 14.33 seconds. The complete  
237 experiment lasted 60 seconds.

238 Table 1 summarizes the number of participants taking part and the stimulus type, size,  
239 and motion presented in each of the three experiments carried out.

240 **Data analysis**

241 Eye position traces were analysed offline using custom software written in MATLAB  
242 (The Mathworks, Inc., Natick, MA, USA). Eye velocity was obtained by differentiation  
243 of the eye position over time and smoothed with a 3-sample window moving average  
244 filter, to reduce the additional noise arising from the differentiation process.<sup>26</sup>

245 Saccades were automatically detected with the adaptive threshold algorithm described  
246 in detail by Behrens et al. (2010). Briefly, this algorithm determines acceleration  
247 thresholds based on the standard deviation of the distribution of 200 preceding  
248 acceleration data values. Saccades are defined and detected as those data points that  
249 exceeded the established threshold. Saccade amplitudes were calculated, and saccades  
250 below 1° amplitude were classified as microsaccades.<sup>27, 28</sup>

251 Periods of smooth pursuit that were free of saccades were plotted and further analysed.  
252 Some authors exclude periods of possible slowed smooth pursuit from their  
253 analysis.<sup>29, 30</sup> In contrast, other authors include all smooth pursuit segments, suggesting  
254 this may offer a better measurement of global smooth pursuit function.<sup>31, 32</sup> In any case,  
255 the difference in gain scores between these two measures has been reported to be less  
256 than 2% with a greater than 0.95 correlation.<sup>32</sup> In this study, we included all smooth  
257 pursuit segments, and the position gain for a given interval of smooth pursuit was  
258 defined as the ratio between the eye position and the target position for this interval.  
259 The position gains obtained from all smooth pursuit segments were averaged to obtain  
260 the mean position gain for each participant.

261 To obtain eye velocity for the constant velocity motions, a linear regression was  
262 performed on each segment of smooth pursuit data, and the slope of the fitted equation  
263 was defined as the eye velocity for that segment. The velocity of each segment was then

264 weighted for the duration of the segment, then velocities were averaged together to  
265 obtain the mean time-weighted velocity for that smooth pursuit task and participant.  
266 Finally, velocity gain was calculated by dividing the time-weighted mean eye velocity  
267 by the stimulus velocity. For the sinusoidal motion paradigm, a polynomial fitting was  
268 performed along the eye position data without the saccades, and the velocity gain was  
269 defined as the coefficient of determination,  $R^2$ , between the smooth pursuit data and the  
270 polynomial fit.

271 The total proportion of smooth pursuit was defined as the total eye movement involving  
272 slow phase (i.e without saccades) divided by the total stimulus movement ( $20^\circ$  for each  
273 smooth pursuit ramp).

#### 274 **Statistical analysis**

275 The IBM SPSS software package version 18.0 (IMB SPSS Inc, Chicago, IL, USA) was  
276 used for statistical analysis. Normality tests were first performed on the data, including  
277 histograms and Shapiro-Wilk tests. In experiment 1, all parameters except the mean  
278 amplitude of the saccades ( $p < 0.001$ ) and the number of microsaccades ( $p < 0.001$ ) were  
279 normally distributed, while in experiment 2, only velocity gain appeared not to be  
280 normally distributed ( $p = 0.004$ ). Hence, parametric t-tests and non-parametric Wilcoxon  
281 test were used accordingly.

282 In experiment 3, only the number of microsaccades was not normally distributed.  
283 Parametric repeated measures ANOVA was still used to statistically analyse all the  
284 parameters in experiment 3, including the number of microsaccades, as ANOVA has  
285 been suggested to be robust to even moderate deviations from normality.<sup>33, 34</sup>

286 For statistical purposes, a  $p$  value lower than 0.05 was considered to be statistically  
287 significant in all three experiments.

## 288 **Results**

### 289 **Experiment 1: Effect of stimulus type on smooth pursuit performance in young** 290 **adults**

291 Figures 4 and 5 show the smooth pursuit performance parameters obtained with the  
292 animated and the standard dot stimuli in each participant. The average smooth pursuit  
293 performance parameters for the animated and the dot stimuli are summarised in Table  
294 2. The animated stimulus produced, on average, higher velocity gains and position gain,  
295 as well as a higher total proportion of smooth pursuit than the standard dot. These were  
296 significantly different from velocity gain ( $t=2.702$ ;  $p=0.014$ ), position gain ( $t=1.441$ ;  
297  $p=0.025$ ) and the proportion of smooth pursuit ( $t=3.544$ ;  $p=0.002$ ) obtained with the  
298 standard dot stimuli. Additionally, fewer saccades were produced during smooth  
299 pursuit with the animated than with the standard dot stimulus ( $t=-2.957$ ;  $p=0.008$ ). In  
300 contrast, Wilcoxon tests revealed that stimulus type had no effect on the mean  
301 amplitude of the saccades ( $Z=-0.342$ ;  $p=0.732$ ) or the number of microsaccades ( $Z=-$   
302  $1.009$ ;  $p=0.313$ ).

### 303 **Experiment 2: Effect of stimulus size on smooth pursuit performance in young** 304 **adults**

305 One participant recruited had an alternating strabismus, and data for this participant  
306 were excluded from the analysis. Figures 6 and 7 show the smooth pursuit performance  
307 parameters obtained from the nine participants. The average smooth pursuit  
308 performance parameters for the 1° and 2° standard dots are summarised in Table 3.  
309 Velocity and position gains as well as the proportion of smooth pursuit have similar  
310 values with each of the two stimuli sizes presented. A Wilcoxon test showed no  
311 differences in velocity gain ( $Z=-1.357$ ;  $p=0.176$ ), and paired t-tests did not reveal any

312 significant differences in position gain ( $t=-0.223$ ;  $p=0.829$ ) or the proportion of smooth  
313 pursuit ( $t=-1.029$ ;  $p=0.334$ ) between the 1° and 2° standard dots.

314 Although the 1° standard dot produced on average fewer saccades and microsaccades  
315 than the 2° standard dot, neither difference was significant (number of saccades:  
316  $t=1.397$ ;  $p=0.211$ ; number of microsaccades:  $t=0.185$ ;  $p=0.858$ ). Moreover, parametric  
317 paired t-tests revealed no significant differences in the mean amplitude of the saccades  
318 ( $t=-0.545$ ;  $p=0.605$ ) between the two stimuli sizes.

### 319 **Experiment 3: Effect of stimulus motion paradigm on smooth pursuit** 320 **performance in children**

321 Figures 8 and 9 show the smooth pursuit performance parameters obtained in each  
322 participant following three different motion paradigms. Repeated measures ANOVA  
323 with a Greenhouse-Geisser correction for sphericity confirmed that velocity gain  
324 ( $F=1.689$ ;  $p=0.222$ ), position gain ( $F=1.479$ ;  $p=0.243$ ), and proportion of smooth  
325 pursuit ( $F=3.213$ ;  $p=0.062$ ) were not significantly different between the ramp, the step-  
326 ramp and the sinusoidal motion paradigms. Similarly, repeated measures ANOVA  
327 showed that the number of saccades ( $F=1.420$ ;  $p=0.265$ ), the mean amplitude of the  
328 saccades ( $F=1.137$ ;  $p=0.341$ ) and the number of microsaccades ( $F=2.824$ ;  $p=0.083$ )  
329 were not significantly different between motion paradigms.

### 330 **Discussion**

331 Different stimuli can be used to study eye movements, but it is reasonable to suggest  
332 that changes in some of their characteristics may affect subjects' overall performance.  
333 A recent study has demonstrated that smooth pursuit and saccadic dynamics can be  
334 improved using cartoon-based stimuli.<sup>13</sup> Such improvement can be attributed to the fact  
335 that more meaningful targets increase attention and therefore impact on oculomotor

336 performance. If this view is correct, the next logical step to further enhance attention  
337 would be to use not only more interesting but also more dynamic stimuli. While this  
338 can perhaps be more easily achieved for saccadic eye movements by using series of  
339 cartoon characters appearing at different locations, more complex and different stimuli  
340 might be needed to maintain attention during smooth pursuit eye movements. Hence,  
341 the first experiment investigated in young adults whether or not more complex and  
342 dynamic stimuli might be a better option to evaluate smooth pursuit eye movements  
343 than the traditional and static stimuli (e.g. dots, cartoons, light spots). The results  
344 revealed that smooth pursuit performance in a young adult population was significantly  
345 improved when using a customised animated stimulus if compared to a standard dot  
346 stimulus. For instance, smooth pursuit gains were found to be significantly higher and  
347 the number of saccades was found to be significantly lower when using the animated  
348 stimulus if compared to a standard dot in a young adult population. Although these  
349 results seem to contradict previous findings, which suggested that stimuli  
350 characteristics have little effect on smooth pursuit performance in adults,<sup>13</sup> our stimulus  
351 is qualitatively different from any stimuli used in previous eye movement research. For  
352 instance, the two stimuli compared by Irving et al. (2011) were similar in that they were  
353 “unchanging stimuli”, while the continuously changing (animated) stimulus presented  
354 here was designed to increase/maintain attention. Hence, our results suggest that using  
355 a dynamic stimulus could improve oculomotor performance in an adult population, and  
356 further studies using such stimuli are warranted.

357 In the first experiment, which aimed to investigate the effect of stimulus type on smooth  
358 pursuit performance, the presentation order of the stimuli was not alternated. Thus, the  
359 animated stimulus was always presented first followed by the unchanging dot stimulus.  
360 It could be argued that this design is not ideal, as maintaining the same presentation



361 order in each participant could have affected the smooth pursuit performance for each  
362 stimulus type. However, the authors chose to always present the animated stimulus first  
363 so that the participants did not have previous experience with the smooth pursuit task,  
364 and therefore any learning effects were avoided when presenting this stimulus. Hence,  
365 if learning effects were present due to the repetition of the smooth pursuit task following  
366 the same motion and velocity, these would have appeared when presenting the  
367 unchanging dot stimulus, resulting in evidence for an improved performance.

368 It has been suggested that the size of the stimulus is also important when evaluating eye  
369 movements, so that large stimuli may elicit an optokinetic response rather than a  
370 voluntary smooth pursuit<sup>35</sup> or saccades might become less accurate.<sup>22, 23</sup> Hence, the  
371 second experiment was designed to evaluate the effect of stimulus size on smooth  
372 pursuit performance. The results showed no significant differences in any of the smooth  
373 pursuit parameters between a 1° and 2° standard dot following a ramp motion paradigm.  
374 These findings agree with previously published results, which suggest that smooth  
375 pursuit performance is independent of stimulus size, unless very large stimuli sizes are  
376 used.<sup>13</sup> Additionally, the smooth pursuit gains obtained for the standard dot stimuli  
377 reported here are similar to those reported in the literature for adults using dots or  
378 similar static stimuli at comparable velocities,<sup>13, 36, 37</sup> and confirm that our young adult  
379 population was not different from previously studied samples. One could argue that  
380 smooth pursuit performance using the dot stimuli was better in experiment 2 than in  
381 experiment 1 and that, therefore, some inconsistencies might be present. However, it is  
382 important to note that two different adult samples of different size (n=20 vs n=10)  
383 participated in each study, and therefore the results from both experiments should be  
384 compared carefully. In any case, there were no statistically significant differences  
385 between the results obtained using the 1° standard dot in experiments 1 and 2. In

386 addition, the results from experiment 2 are in agreement with previous  
387 literature<sup>22, 23</sup> and further support the idea that eye movements are not dependant on  
388 stimulus size, at least for moderate stimulus sizes.

389 Finally, in the third experiment, we assessed the effect of different motion paradigms  
390 on smooth pursuit performance in a group of children using the animated stimulus.  
391 There were three reasons for undertaking this experiment in a group of children. First,  
392 the characteristics of our novel animated stimulus were designed to increase/maintain  
393 participants' attention, with the expectation that this stimulus might be particularly  
394 salient to children. Second, stimulus characteristics seem to have a higher impact in  
395 children than in adults,<sup>13</sup> and thus our stimulus might be expected to improve their  
396 oculomotor performance. Third, while most studies have used ramp paradigms to  
397 investigate smooth pursuit in adults,<sup>15-17</sup> studies in children have used various motion  
398 paradigms, and therefore their results are often not comparable.<sup>6-8, 18, 19</sup> Further  
399 complicating matters, it has been suggested that step-ramp motions are more  
400 appropriate for infants and young children,<sup>38</sup> while sinusoidal motions are a better  
401 option for school age children.<sup>6, 20</sup> However, these suggestions seem to be based more  
402 on the authors' opinions and preferences than on scientific evidence. Interestingly, the  
403 values obtained for all the smooth pursuit parameters studied here were similar across  
404 the three different motions presented, and in fact, no significant differences were found  
405 between any of the motion paradigms. Hence, the motion paradigm used seemed to  
406 have little or no effect on smooth pursuit performance in children, at least with the  
407 animated stimulus presented here.

408 Overall, our results demonstrate that, contrary to previous studies, smooth pursuit  
409 performance can be improved in young adults with a more interesting and/or interactive  
410 stimulus. Of course, one could argue that the differences in smooth pursuit performance

411 found in experiment 1 between the animated and the unchanging dot stimuli could arise  
412 from the stimulus size, as these two were different in size. However, the results from  
413 experiment 2 showed that size of the stimulus (1° vs 2°) did not significantly affect  
414 smooth pursuit performance in a young adult population, supporting the view that the  
415 differences found in the previous experiment were due to the type rather than the size  
416 of the stimulus. Although the effects of stimulus type were studied here only in a young  
417 adult population, the improvement is likely to be even more evident in children.

## 418 **Conclusion**

419 Finally, this is an innovative and unique study as, to our knowledge, it is the first time  
420 that an animated stimulus has been utilised to study eye movements in adults and  
421 children. Although this study has focussed on smooth pursuit eye movements, the  
422 results may well be extrapolated generally to other eye movements and offer the  
423 possibility that performance can be improved significantly with attention-grabbing and  
424 dynamic (i.e. animated) stimuli. Therefore, we recommend the use of animated stimuli  
425 for the evaluation of smooth pursuit and fixation stability and further support the idea  
426 of using cartoon pictures as stimuli for saccades,<sup>13</sup> especially in children. Of course, the  
427 importance of the choice of stimuli to evaluate eye movements should not only be  
428 considered for research purposes but also in clinical settings.

## 429 **Acknowledgements**

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431 Sciences, Cardiff University) for their technical and programming assistance.

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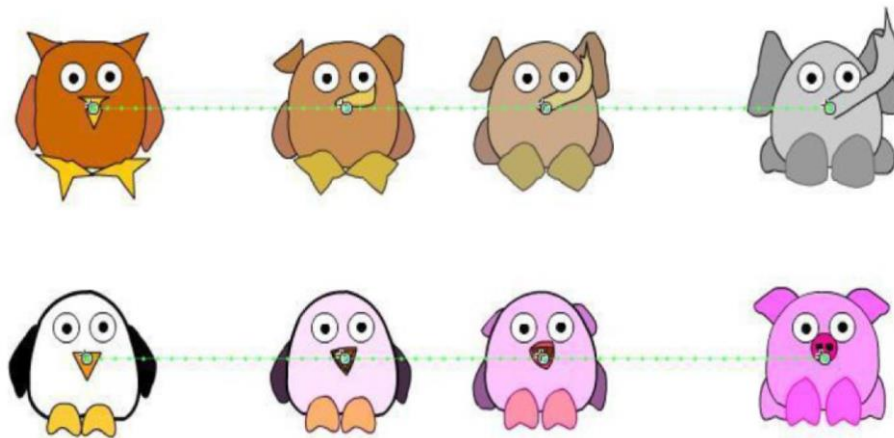
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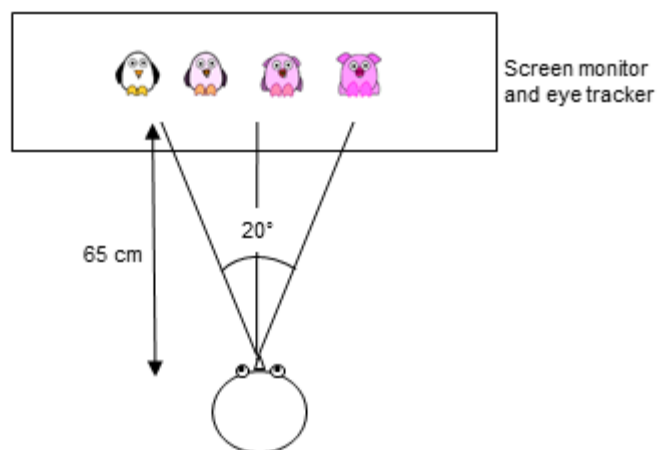
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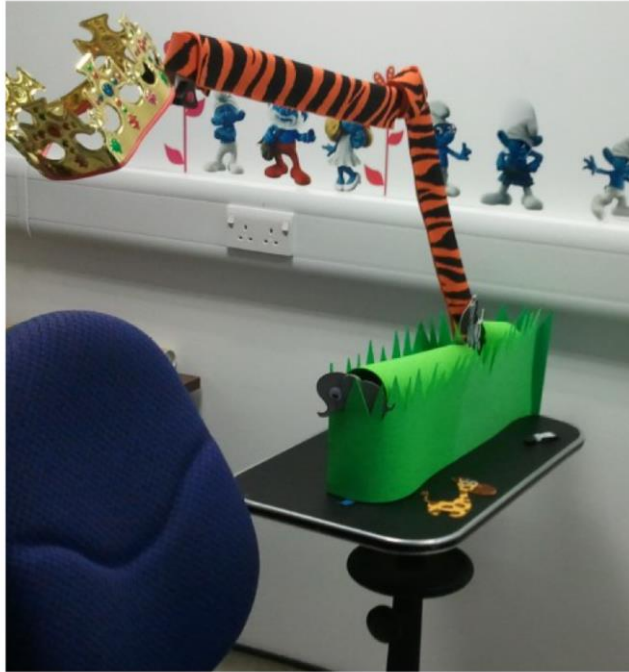


**Figure 1.** Customised animated stimulus.

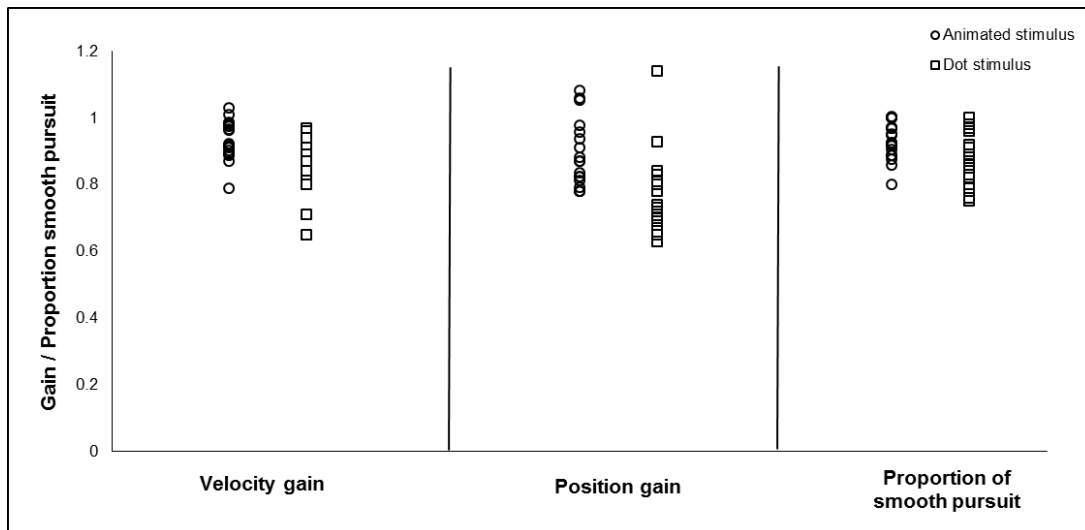


**Figure 2.** Diagram of the setup illustrating the distance of the eye-tracker from subject and the amplitude of the stimulus movement.

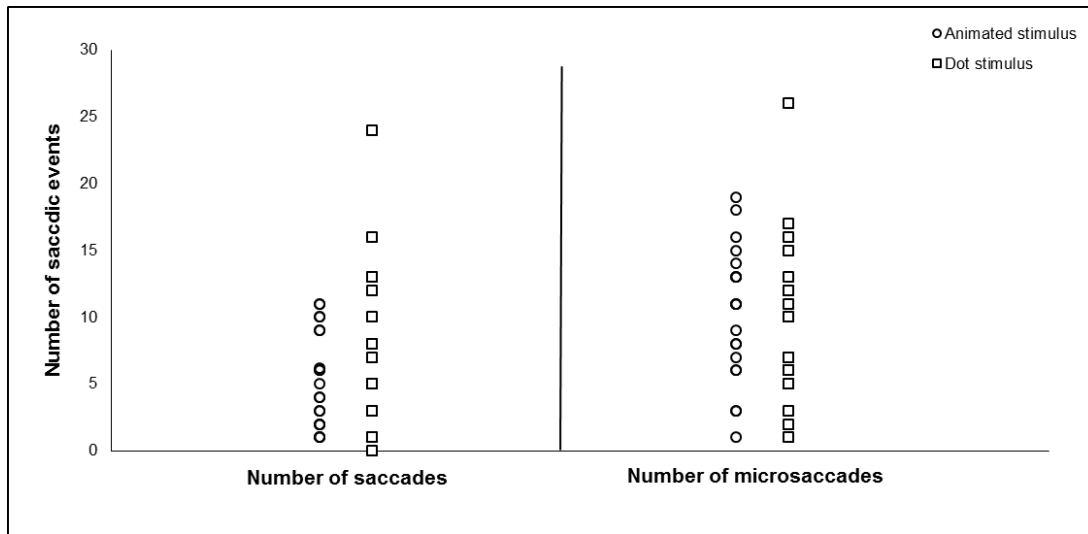




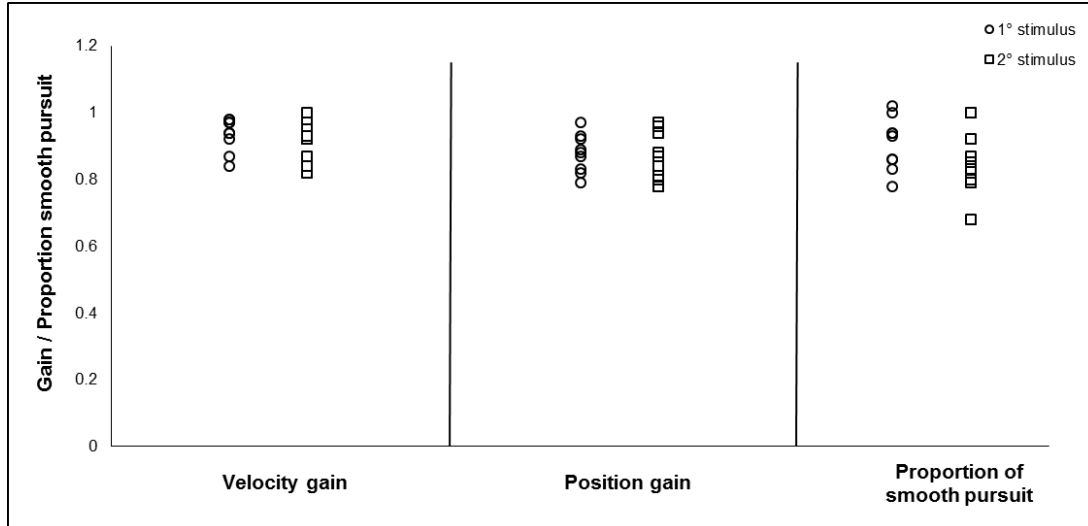
**Figure 3.** Customised child-friendly head stabiliser.



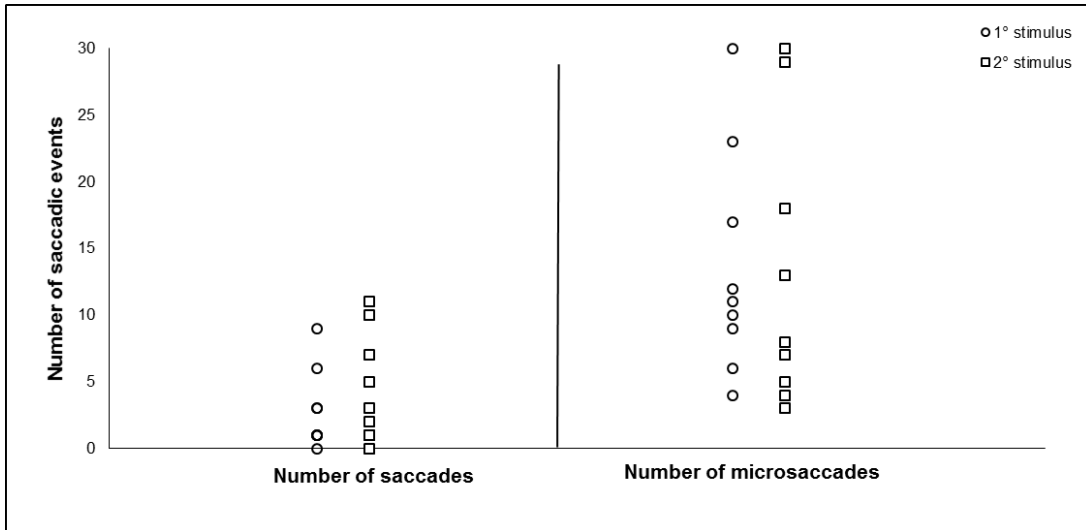
**Figure 4.** Velocity gain, position gain and proportion of smooth pursuit obtained from 20 young adults using the 2° animated stimulus (circles) and the 1° standard dot (squares).



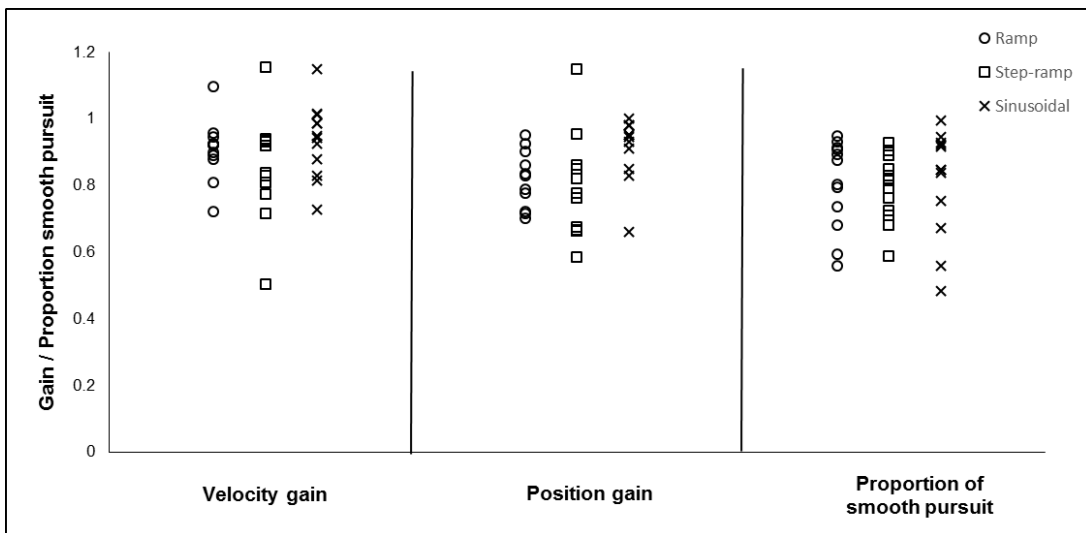
**Figure 5.** Number of saccades and microsaccades obtained from 20 young adults using the 2° animated stimulus (circles) and the 1° standard dot (squares).



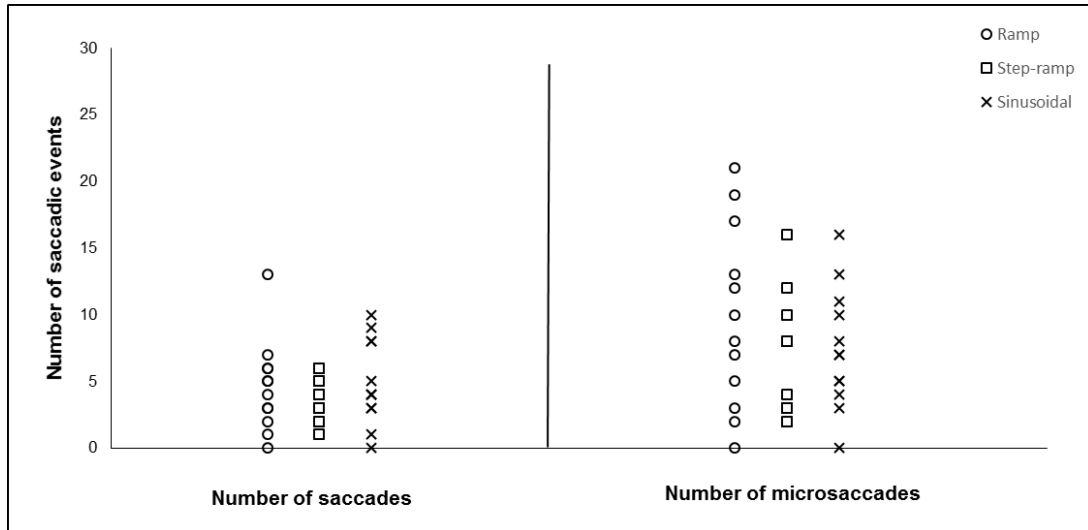
**Figure 6.** Velocity gain, position gain and proportion of smooth pursuit obtained from 9 young adults using the 1° dot (circles) and for the 2° dot stimulus (squares).



**Figure 7.** Number of saccades and microsaccades obtained from 9 young adults using the 1° standard dot (circles) and for the 2° standard dot stimulus (squares).



**Figure 8.** Velocity gain, position gain and proportion of smooth pursuit obtained from 12 children using the animated stimulus following a ramp (circles), step-ramp (squares) and sinusoidal (crosses) motion paradigms.



**Figure 9.** Number of saccades and microsaccades obtained from 12 children using the animated stimulus following a ramp (circles), step-ramp (squares) and sinusoidal (crosses) motion paradigms.

**Supplemental Digital Content 1.** Video that shows the eye movement recording of a 4 year old child using our customised setup and animated stimulus. mov

**Table 1.** Summary of the participants taking part, stimulus type and motion presented in each experiment

	Participants	Stimulus type	Stimulus motion
Experiment 1	20 adults	2° animated	6°/sec ramp
		1° standard dot	
Experiment 2	10 adults	1° standard dot	6°/sec ramp
		2° standard dot	
Experiment 3	12 children	2° animated	6°/sec ramp 6°/sec step-ramp Sinusoidal

**Table 2.** Mean values for each smooth pursuit parameter obtained from twenty young adults using the animated and the dot stimuli.

Smooth pursuit parameters	Animated stimulus Mean; 95% CI	Dot stimulus Mean; 95% CI	P
Velocity gain	0.93; 0.90-0.96	0.87; 0.82-0.92	<b><i>p=0.014</i></b>
Position gain	0.93; 0.85-1	0.82; 0.72-0.92	<b><i>p=0.025</i></b>
Proportion of smooth pursuit	0.94; 0.91-0.96	0.872; 0.83-0.90	<b><i>p=0.002</i></b>
Number of saccades	5.30; 3.64-6.96	7.75; 5.03-10.46	<b><i>p=0.008</i></b>
Mean amplitude of saccades	1.41; 1.16-1.66	1.34; 1.13-1.55	<i>p=0.732</i>
Mean number of microsaccades	10.25; 7.90-12.60	9.50; 6.68-11.31	<i>p=0.313</i>

**Table 3.** Mean values for each smooth pursuit parameter obtained from nine young adults using a 1° and a 2° dot stimuli.

Smooth pursuit parameters	1° dot stimulus Mean; 95% CI	2° dot stimulus Mean; 95% CI	p
Velocity gain	0.93; 0.89-0.97	0.91; 0.86-0.96	<i>p</i> =0.176
Position gain	0.87; 0.83-0.92	0.87; 0.81-0.92	<i>p</i> =0.829
Proportion of smooth pursuit	0.90; 0.84-0.96	0.86; 0.78-0.93	<i>p</i> =0.334
Number of saccades	2.77; 0.51-5.04	4.44; 1.31-7.56	<i>p</i> =0.211
Mean amplitude of saccades	1.23; 1.07-1.39	1.19; 1.09-1.28	<i>p</i> =0.605
Mean number of microsaccades	14.22; 6.57-21.86	15.55; 3.15-27.95	<i>p</i> =0.858