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Running Title: Eye-tracking Cycling Time-Trials

1 **Information acquisition differences between experienced and novice time trial cyclists**

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23 in this study constitute endorsement by the American College of Sports Medicine.

24

25 **Abstract**

26 **Purpose:** To use eye-tracking technology to directly compare information acquisition behavior of
27 experienced and novice cyclists during a self-paced 10 mile (16.1 km) time-trial. **Method:** Two groups
28 of novice (N=10) and experienced cyclists (N=10) performed a 10-mile self-paced time-trial (TT) on two
29 separate occasions during which a number of feedback variables (speed, distance, power output,
30 cadence, heart rate, and time) were projected within their view. A large RPE scale was also presented
31 next to the projected information and participants. Participants were fitted with a head-mounted eye-
32 tracker and heart rate monitor. **Results:** Experienced cyclists performed both time-trials quicker than
33 novices ($F_{1,18}=6.8$, $P=.018$) during which they primarily looked at speed (9 of 10 participants) whereas
34 novices primarily looked at distance (6 of 10 participants). Experienced cyclists looked at primary
35 information for longer than novices across the whole time-trial ($24.5\pm 4.2\%$ vs. $34.2\pm 6.1\%$, $t_{18}=4.2$,
36 $P<0.001$) and less frequently than novices during the last quarter of the time-trial (49 ± 19 vs. 80 ± 32 , $t_{18}=-$
37 2.6 , $P=0.009$). The most common combination of primary and secondary information looked at by
38 experienced cyclists was speed and distance respectively. Looking at ten different primary-secondary
39 feedback permutations, the novices were less consistent than the experienced cyclists in their
40 information acquisition behavior. **Conclusion:** This study challenges the importance placed on
41 knowledge of the endpoint to pacing in previous models, especially for experienced cyclists for whom
42 distance feedback was looked at secondary to, but in conjunction with, information about speed. Novice
43 cyclists have a greater dependence upon distance feedback, which they look at for shorter and more
44 frequent periods of time than the experienced cyclists. Experienced cyclists are more selective and
45 consistent in attention to feedback during time-trial cycling.

46 **Keywords:** Performance; Pacing; Cycling; Vision; Cognition; Decision

47

48 **Introduction**

49 **(Paragraph 1)** It is important for athletes to employ their available energy effectively to perform
50 optimally and avoid fatigue during exercise, so that “all energy stores are used before finishing a race,
51 but not so much that a meaningful slowdown occurs.” (8,18,29) Pacing strategy is an essential aspect of
52 competitive prolonged athletic performance and refers to the variation of speed during an event by
53 regulating the rate of energy expenditure (18–21,28). Where completion time is the measure of success,
54 pacing strategy has an influence over success in events lasting longer than 60 seconds (1).

55 **(Paragraph 2)** Several factors are known to influence the pacing strategy that an athlete adopts
56 including the duration of the event (8), presence of a competitor (7,57), environmental conditions (41),
57 previous experience (35), perceptions of exertion (49), and the availability and veracity of performance
58 feedback information (14,36). Previous models of pacing place a lot of emphasis on an athlete’s
59 awareness of changes to the internal physiological state of their body, experienced as perceived exertion,
60 in relation to their progress towards the endpoint as informed through various forms of feedback.
61 According to Teleoanticipation Theory (50) and later on the Central Governor Model (40), a ‘central
62 governor’ anticipates exercise and presets a pacing strategy based on the end-point or duration of
63 exercise. In a more recent manifestation of Central Governor Model, more complex information-
64 processing mechanisms have been proposed in which rate of change of perceived exertion is evaluated in
65 the light of expected duration or distance of an event and modified through appropriate alternations in
66 pace (48). The Psychobiological Model similarly supports the notion of effort-related decisions about
67 pace in the context of event duration, but argues that such decisions are entirely conscious and that
68 subconscious processes, such as those proposed by the Central Governor Model, are inapposite (34). The
69 linear relationships found between RPE and the proportion of completed event, are such that the RPE
70 gradient was found to peak in coincidence with the expected endpoint (15,19,31).

71 **(Paragraph 3)** In an attempt to factor for varying uncertainty about pace during endurance events, a
72 model has been specified whereby risk is expressed as the proportion of the remaining task multiplied by
73 their momentary RPE, a variable the authors refer to as hazard score (9). An appealing feature of the
74 hazard score model is that the further an athlete progresses, the lower hazard score becomes, thus
75 explaining how athletes are sometimes able to risk performing very intense spurts of energy towards the
76 end of an event when the risk of not-completing as a consequence of doing so is relatively low. An
77 alternative model proposed that pacing decisions are based upon the estimated time that present power
78 output can be maintained, as judged against the duration or length of the task (23). More recent
79 suggestions of how pace is regulated have drawn on the decision-making literature (42) and the
80 interdependence of perception and action in attempting to account for pacing behavior in
81 environmentally complex situations (45).

82 **(Paragraph 4)** Whatever theory of pacing is subscribed to, all emphasize knowledge of proximity to the
83 endpoint as a key determinant of pacing strategy. However, the importance placed on endpoint
84 knowledge in pacing models is based on experimental evidence that was collected using limited indirect
85 observation methods where participants have been deceived about, or deprived of, progression or
86 performance feedback information (30). A number of studies have used false feedback about distance or
87 time to understand the importance of feedback and the use of knowledge during exercise. Studies have
88 found that deceiving athletes about the duration of exercise, by providing false or no knowledge about
89 the exercise endpoint, leads to increased RPE and a different pacing strategy caused by an incorrect
90 allocation of physiological resources (3,12). Experience of using blind, true and false performance
91 feedback has also been found to provoke different types of learnt pacing strategies (38).

92 **(Paragraph 5)** Feedback deception and blinding experimental methods have been the dominant
93 approaches used to understand how athletes use information to pace themselves. Deductions about the

94 significance and role of particular types of performance information are made based upon what happens
95 to pace if that information is altered or removed. The underlying logic is that if, after altering or
96 removing a particular source of information pacing or performance worsens, then it can be inferred that
97 that information source has an important contributory role. It has been this approach that has led to the
98 emphasis placed on knowledge of the endpoint in various pacing models.

99 **(Paragraph 6)** There are several limitations to this information-knockout approach. The first is the focus
100 on singular sources of information and the lack of investigative sophistication in understanding how
101 athletes interpret various sources of information in conjunction with each other. For example, the
102 importance athletes place on speed or power information to make pacing decisions could potentially vary
103 according to how much time or distance has elapsed, or according to environmental conditions or
104 competitor behavior. A further, but related, limitation is that knockout and deception studies have not
105 investigated within-trial changes in the emphasis placed on certain types of feedback. For example,
106 potentially an athlete may be more concerned with average speed in the first half of a race and then
107 become more interested in elapsed time or distance towards the end of an event. The final limitation is
108 the inability to understand individual differences in feedback preferences, which could vary according to
109 past experience or the outcome measure by which they appraise their achievement success. A threat to
110 the validity of previous pacing models is the reliance on limited deception and blinding methods, which
111 necessitated indirect interpretation regarding the importance of endpoint awareness as a determinant of
112 athletic pace. It is this point that the present study intended to redress.

113 **(Paragraph 7)** A more direct method of measuring what information athletes seek and use during self-
114 paced exercise will greatly improve our understanding of pacing decisions and, to our knowledge, this
115 have never been achieved. In one study the frequency with which children looked at elapsed time during
116 a time-limited run was measured from a video recording and it was found that they looked at the watch

117 more often towards the end of the run (6). While the methods of measuring information acquisition in
118 this study were quite basic, eye-tracking technology does provide a more sophisticated method of
119 directly measuring what information athletes look at during self-paced exercise. Unlike previous
120 deception and information-knockout studies, the precision with which information acquisition behavior
121 can be measured using eye-tracking technology is able to overcome the limitations of deception studies
122 discussed earlier. Importantly, eye-tracking enables detailed information to be gathered about how
123 athletes acquire information in dynamic and conjunctive ways during an exercise trial, as well as how
124 they learn to use information differently with experience to pace themselves.

125 **(Paragraph 8)** The use of eye-tracking technology in sport is a powerful method (11) that has enabled
126 researchers to develop better insights about perceptual-cognitive mechanisms of sport performance (24,
127 33). Mobile eye-tracking technology has proven especially versatile in allowing researchers to collect
128 data in many different sports domains where performance is dependent upon the ability perceive and
129 process complex information in often fast moving environments. In such situations, the visual is the
130 dominant mode of sensory feedback in the perceptual-action coupling (32), a system in which attention
131 to external cues enables the kind of adaptive movements required for the successful performance of
132 motor tasks such as catching or striking a ball. In the context of cycling, eye-tracking has provided
133 useful insights about the role of visual behaviour in balance and steering (51, 53) but has not been used
134 to understand information pick-up as part of the perceptual-action processes in regulating pace (45).
135 Eye-tracking technology has also provided considerable insights about differences in perceptual-
136 cognitive mechanisms between expert and novice performers (24, 55), and this approach has great
137 potential in developing a better understanding of information acquisition and decision-making during
138 self-paced cycling. Generally, previous research has suggested that experts across many sports domains
139 tend to look at task-relevant information less frequently and for less time than novices (24,27). This has

140 a relevance to pacing theory because it raises the question of whether differences exist between expert
141 and novice cyclists about what information feedback they consider to be task relevant, and whether
142 differences exist in how frequently they refer to such information and for how long.

143 **(Paragraph 9)** While we acknowledge that the use of eye-tracking technology is fairly common-place in
144 sport domains and expertise research, the present study used eye-tracking technology in an original way
145 to better understand information acquisition and pacing behaviour in cyclists. The purpose was, for the
146 first time, to directly measure what information cyclists look at while performing a time-trial, and to
147 compare the information-acquisition strategies of novice and experienced cyclists. We hypothesized that
148 experienced cyclists would look at fewer sources of information, and would seek out information less
149 frequently compared to novices.

150 **Methods**

151 *Participants*

152 **(Paragraph 10)** Experienced (n=10) and novice male cyclists (n=10) were recruited for this study from
153 the University of Essex and local cycling clubs. Mean \pm 1SD age, stature and body mass for the
154 experienced cyclists was 38.6 ± 11.3 years, 176.6 ± 6.9 cm and 74 ± 9.4 kg for the experienced cyclists,
155 and for the novice cyclists was 36.1 ± 9.9 years, 178.5 ± 6.7 cm and 80.2 ± 8.7 kg. The experienced
156 cyclists were recruited from local cycling clubs and had participated in competitive 16.1 km time-trials
157 for an average of 14.1 ± 13 years. During the 6 months preceding the study, the experienced cyclists had
158 on average trained each week on 4.7 ± 1.1 occasions for a total of 8.5 ± 2.1 hours. The novice cyclists
159 were recruited from the University of Essex staff and students and, although they could all ride a bicycle,
160 they had never trained for, or participated in competitive cycling events of any kind. In an attempt to
161 control for fitness, only physically active individuals were recruited to the novice group who had on
162 average trained each week on 2.8 ± 0.8 occasions for a total of 4.6 ± 1.1 hours across a range of different

163 sports that did not involve cycling. Each participant provided written informed consent to take part in
164 this study, which was approved by the University of Essex ethics committee.

165 *Design*

166 **(Paragraph 11)** A two-way mixed experimental design (experience-by-segment) was used in which we
167 compared pace, performance and visual information acquisition between novice and experienced cyclists
168 (between-subjects experience factor) during a 16.1 km cycling time-trial every 4 km (within-subjects
169 segment factor). All participants performed a 16.1 km familiarization time trial (TT_{FAM}) and then had a
170 recovery period of 5 to 10 days before completing the 16.1 km experimental time-trial (TT_{EXP}). During
171 each time-trial completion time (s), speed ($\text{km}\cdot\text{hr}^{-1}$), power output (W), distance (km), pedaling cadence
172 ($\text{r}\cdot\text{min}^{-1}$) and heart rate ($\text{b}\cdot\text{min}^{-1}$) was measured. RPE was recorded every 4 km. Participants wore a
173 monocular eye-tracking device for familiarization purposes during TT_{FAM} and then to measure the type,
174 duration and frequency of information they looked at during TT_{EXP} .

175 *Procedure*

176 **(Paragraph 12)** Before each time-trial participants were asked to refrain from ingesting caffeine for at
177 least 6 hours, alcohol for 24 hours and food for 2 hours prior to testing. Participants were also asked not
178 to train or engage in heavy physical work for 24 hours before testing. On the first laboratory attendance
179 each participant had their body mass and stature measured and was briefed as to the requirements of the
180 trial but not the purpose of the study. Participants also completed a short training history questionnaire.
181 After all tests had been completed, participants were debriefed about the purpose of the study.

182 *Cycling Ergometry and Video Simulation*

183 **(Paragraph 13)** All cycling tests were performed on a Velotron (3D) Racer Mate ergometer with
184 RealVideo simulation software (Racermate, Seattle). The 16.1 km time-trial duration was selected as this
185 is a common format used in the UK and one which the experienced cyclists used in this study were most

186 accustomed. All cycling tests were performed at the same time of day \pm one hour to control for circadian
187 variation in outcome measures. Prior to each time-trial, participants performed a standardized 5-minute
188 self-paced warm-up. Participants were instructed to complete the time-trial in the fastest possible time.
189 They were not provided with any information acquisition or pacing guidance.

190 **(Paragraph 14)** During each time-trial, a RealVideo simulated cycling course was projected onto a wall
191 in front of and slightly offset to the right of the cycling. The projected video footage was coupled in a
192 multiplicative way to the cyclists' actual power output such that any alteration in speed was instantly
193 represented on the screen. Notwithstanding minor projector repositioning variances, the projected screen
194 size was 2.1 m wide by 1.5 m high with the bottom border of the projection running 1 m above and
195 parallel to the floor. The cycle ergometer was positioned such that the handlebar stem riser was 3 m
196 perpendicular to the plane of the screen which itself was offset to the right of the natural forward field of
197 vision of the cyclists with a vector displacement of 8° at 3.03 m for the left border of the projection and
198 40° at 3.91 m for the right border (visual arc 32°). Offsetting the screen in this way required participants
199 to rotate their neck to look at the projected information, thus adding confidence that the eye-tracking
200 measurements constituted deliberate attempts to acquire information, rather than information glances just
201 because it happened to fall naturally within participants forward field of vision.

202 **(Paragraph 15)** Incorporated into the projection beneath the simulated time-trial video, were five fields
203 of real-time feedback information which, presented from left to right, were speed ($\text{km}\cdot\text{hr}^{-1}$), elapsed
204 distance (km), power output (W), pedaling cadence ($\text{r}\cdot\text{min}^{-1}$) and heart rate ($\text{b}\cdot\text{min}^{-1}$). The row of five
205 feedback information fields were 0.375 m above and parallel to the bottom border of the projection or
206 1.375 m above the floor. The vector displacement of the center of each information field from the
207 handlebar stem riser was speed (9.5° , 3.04 m), elapsed distance (18.1° , 3.16 m), power output (26.0° ,
208 3.34 m), pedaling cadence (32.9° , 3.57 m) and heart rate (38.9° , 3.86 m). Elapsed time (min:sec) was

209 displayed above the heart rate field (3.0°, 0.2 m). The block size of individual characters within each
210 field was 4.5 cm high by 2.9 cm wide. Angular separation of the information fields was at its most acute
211 3° (elapsed time – heart rate) and at its least acute 8.6° (elapsed distance - speed), well beyond the
212 manufacturer-defined eye-tracker spatial resolution of 0.1° and gaze position accuracy within the nearest
213 degree. The size and separation of the projected information blocks therefore facilitated clear
214 differentiation in eye-tracker measurements as later described. An A0 sized RPE scale was also
215 displayed to the left of the projector screen.

216 *Psychophysiological Measures*

217 **(Paragraph 16)** Heart rate (HR) was recorded during both cycling time-trials every (120) milliseconds
218 using a chest strap Polar Accurex Plus heart rate monitor (Polar Electro, Kempele, Finland) connected
219 via wireless to the Velotron software. Average HR was calculated every 4 km. Participants were asked to
220 provide an overall rating of perceived exertion every 4 km using the Borg 6-10 RPE scale (5). All
221 subjects were familiarised with the RPE scale, which was administered in accordance with published
222 standardised instructions (4).

223 *Eye-Tracking and Video Analysis*

224 **(Paragraph 17)** Participants were fitted with a SensoMotoric Instruments SMI iViewX head-mounted
225 monocular eye-tracking device (HED). The system consists of two cameras mounted on a cycling
226 helmet, one that records the eye position of the participant, and a 3.6 mm wide-angle forward-looking
227 camera that records the scene the participant is looking at. Eye position was recorded at 50 Hz, which
228 was then down-sampled to 25 frames per second for the resulting scene videos. The eye-tracker was
229 calibrated using the participant's left eye in accordance with the manufacturer's instructions by asking
230 participants to fixate a series of markers spanning the area of the display. Calibration accuracy was
231 checked sporadically and at the end of the time trial by asking the participant to fixate points on the

232 screen and information display. The equipment has a manufacturer-defined spatial resolution of 0.1° and
233 tests demonstrated that gaze position was accurate to within the nearest degree. The system tracks eye
234 movements using pupil and corneal reflex so that each participant's point of regard can be superimposed
235 onto the recorded scene, thus enabling timed measurements to be made of eye fixations.

236 **(Paragraph 18)** The eye-tracking videos for TT_{EXP} were subsequently reviewed and manually coded by
237 the first author. Manual coding of eye-tracking data remains the state-of-the-art in active tasks, (52) and
238 within-coder comparisons indicated that gaze location could be determined unambiguously. Reliability
239 of similar methods have shown very good inter-rater reliability (22). Due to the relatively low sampling
240 rate of the eye-tracker, saccades could not be automatically detected, but fixations were only coded when
241 data was within the same region for at least 3 frames (\cong 100 ms). Eye gaze was coded by recording the
242 start and end frame of each entry into a new region of interest. This allowed us to determine the periods
243 of time spent inspecting each of then eye fixation times were manually recorded in milliseconds against
244 nine predetermined categories. Six of the categories related to information feedback that were speed,
245 elapsed distance, power output, cadence, heart rate and elapsed time. Eye fixation times were also
246 recorded for the rating of perceived exertion and the video simulation of the time-trial course that was
247 projected onto the wall. A final category was created to capture all other objects of regard not
248 corresponding to the other eight categories, for example, when participants looked at the laboratory floor
249 or at laboratory equipment. Fixations of less than 3 frames, blinks and other periods of data loss (e.g.
250 when participants looked at extreme angles) were also included in the 'other' coding category. This
251 procedure allowed detailed coding of point of regard for the whole length of the time trial.

252 ***Data Processing and Statistical Analysis***

253 **(Paragraph 19)** Total gaze time and gaze frequency for each of the nine categories (speed, elapsed
254 distance, power output, cadence, heart rate, elapsed time, video simulation and other) was calculated on

255 a participant-by-participant basis for the whole time-trial and for each 4 km segment. Gaze frequency,
256 defined as the number of separate eye fixations for each category, and total gaze time, defined as the
257 accumulated time of all eye fixations for each category, were calculated for each participant across the
258 whole time-trial and for each segment. Total gaze times were then used to determine what information
259 source that each participant looked at for longest accumulated average time (primary), second longest
260 accumulated average time (secondary), third longest accumulated average time (tertiary) and so on until
261 quaternary (4th), quinary (5th), senary (6th), septenary (7th), octonary (8th) and nonary (9th) had all been
262 established. To normalize absolute total gaze times for inter-participant differences in time-trial
263 performance, primary to nonary fixation data were all converted from absolute time (ms) to percentage
264 of time-trial completion time.

265 **(Paragraph 20)** Time-trial average cycling speed (performance) interactions between experienced and
266 novice cyclists, and between the first and second time-trials was analysed using two-way mixed
267 ANOVAs. Three-way mixed ANOVAs were used to analyse group-by-trial-by-segment interactions in
268 average cycling speed (pace) as well as relative fixation time and gaze frequency for the primary,
269 secondary and tertiary visual categories.

270 **(Paragraph 21)** For both performance, pace and visual data, significant interactions were followed up
271 using planned post-hoc comparisons between segments using paired-samples *t* tests for within-group
272 comparisons and independent sample *t* tests for between-group comparisons. Paired-samples *t* tests were
273 also used to compare within group comparison and RPE values. All results are expressed as mean (SD)
274 and effect sizes as partial eta squared.

275 **Results**

276 ***Time Trial Performance, Heart Rate and RPE***

277 **(Paragraph 22)** Two-way mixed ANOVAs revealed the following experience and trial factor outcomes.
 278 Average cycling speed: No group-by-trial interaction ($F_{1,18}=2.7$, $P=.082$, $\eta_p^2=.16$) but there was a group
 279 main effect ($F_{1,18}=6.8$, $P=.018$, $\eta_p^2=.27$) and a trial main effect ($F_{1,18}=11.2$, $P=.004$, $\eta_p^2=.38$). Completion
 280 time: No group-by-trial interaction ($F_{1,18}=2.7$, $P=.082$, $\eta_p^2=.16$) but there was a group main effect
 281 ($F_{1,18}=6.8$, $P=.018$, $\eta_p^2=.27$) and a trial main effect ($F_{1,18}=11.2$, $P=.004$, $\eta_p^2=.38$). Average power output:
 282 No group-by-trial interaction ($F_{1,18}=0.6$, $P=.440$, $\eta_p^2=.03$) but there was a group main effect ($F_{1,18}=10.8$,
 283 $P=.004$, $\eta_p^2=.38$) and a trial main effect ($F_{1,18}=11.6$, $P=.003$, $\eta_p^2=.39$). Average pedaling cadence: No
 284 group-by-trial interaction ($F_{1,18}=0.1$, $P=.740$, $\eta_p^2<.01$) or trial main effect ($F_{1,18}=3.6$, $P=.07$, $\eta_p^2=.17$) but
 285 there was a group main effect ($F_{1,18}=12.7$, $P=.002$, $\eta_p^2=.414$). Average heart rate: No group-by-trial
 286 interaction ($F_{1,18}=0.3$, $P=.086$, $\eta_p^2<.01$), no group main effect ($F_{1,18}<0.1$, $P=.945$, $\eta_p^2<.01$) and no trial
 287 main effect ($F_{1,18}=0.2$, $P=.646$, $\eta_p^2=.01$). Average RPE: No group-by-trial interaction ($F_{1,18}<0.1$, $P=.929$,
 288 $\eta_p^2<.01$), no group main effect ($F_{1,18}=0.4$, $P=.518$, $\eta_p^2=.02$) and no trial main effect ($F_{1,18}=0.9$, $P=.361$,
 289 $\eta_p^2=.05$). Group and trial differences in performance, heart rate and RPE variables are presented in
 290 Figure 1A, with post-hoc statistical outcomes indicated for significant differences between novice and
 291 experienced cyclists (independent samples t-tests) and between familiarization and experimental time-
 292 trials (paired samples t-tests).

293 ***Segment Comparisons of Performance, Heart Rate and RPE***

294 **(Paragraph 23)** There were no group-by-trial-by-segment interactions or two-way interactions for
 295 speed, completion time, power, cadence, heart rate or RPE. Trial main effects were found for speed
 296 ($F_{1,18}=12.9$, $P=0.002$, $\eta_p^2=.42$), completion time ($F_{1,18}=12.9$, $P=0.002$, $\eta_p^2=.42$) and power ($F_{1,18}=11.5$,
 297 $P=0.003$, $\eta_p^2=.39$). Segment main effects were found for speed ($F_{3,54}=4.3$, $P=0.009$, $\eta_p^2=.19$), completion
 298 time ($F_{3,54}=4.3$, $P=0.009$, $\eta_p^2=.19$), power ($F_{3,54}=6.9$, $P=0.001$, $\eta_p^2=.28$), heart rate ($F_{3,54}=101$, $P<0.001$,
 299 $\eta_p^2=.85$) and RPE ($F_{3,54}=518$, $P<0.001$, $\eta_p^2=.97$). Group main effects were found for speed ($F_{1,18}=7.9$,

300 $P=0.012$, $\eta_p^2=.31$), completion time ($F_{1,18}=7.9$, $P=0.012$, $\eta_p^2=.31$), power ($F_{1,18}=10.8$, $P=0.004$, $\eta_p^2=.38$)
301 and cadence ($F_{1,18}=12.7$, $P=0.002$, $\eta_p^2=.414$). Post hoc independent samples t-tests found experienced
302 cyclists were faster than novices during every time-trial segment, in both TT_{FAM} and TT_{EXP} . Group and
303 segment differences in pace with post-hoc outcomes are presented in Figure 1B for TT_{FAM} and in Figure
304 1C for TT_{EXP} . Mean and standard deviation data for speed, completion time, power, cadence, heart rate
305 and RPE are given in Table 1 for each group, time-trial and segment along with post hoc statistical test
306 outcomes.

307 ***Whole Time-Trial Eye-Tracking Outcomes: Total Gaze Duration and Gaze Frequency***

308 **(Paragraph 24)** Novice and Experienced mean total gaze duration data for primary through to nonary
309 points of regard were calculated over the full 16.1 km for TT_{EXP} and are presented in Figure 2A. A two-
310 way mixed ANOVA found a group-by-point of regard interaction for total gaze duration (% time-trial
311 duration), $F_{8,144}=10.9$, $P<0.001$, $\eta_p^2=.38$. Independent-samples post-hoc t-tests revealed that experienced
312 cyclists looked at primary points of regard for longer than novices during TT_{EXP} ($34.2 \pm 6.1\%$ vs.
313 $24.5 \pm 4.2\%$, $t_{18}=-4.2$, $P<0.001$, $\eta^2=0.49$). Other experienced vs. novice post-hoc outcomes for total gaze
314 time are represented in Figure 2A.

315 **(Paragraph 25)** The frequency of which novice and experienced participants looked at primary through
316 to nonary points of regard was counted overall for TT_{EXP} and is presented in Figure 2B. A two-way
317 mixed ANOVA found a group-by-point of regard interaction for gaze frequency, $F_{8,144}=2.2$, $P=0.03$,
318 $\eta_p^2=0.11$. Independent-samples post-hoc t-tests revealed that experienced cyclists looked at information
319 less frequently than novices (Figure 2B).

320 ***Time-Trial Segment Eye-Tracking Outcomes: Total Gaze Duration and Frequency***

321 **(Paragraph 26)** Segment changes in gaze duration and gaze frequency were analysed using two-way
322 mixed ANOVAs for primary, secondary and tertiary points of regard. Group main effects were found for

323 total gaze duration for the primary point of regard ($F_{1,18}=16$, $P<0.001$, $\eta_p^2=0.47$) and the secondary point
324 of regard ($F_{1,18}=6.7$, $P=0.02$, $\eta_p^2=0.27$) but not the tertiary point of regard. No segment main effects or
325 segment-by-group interactions were found for primary, secondary or tertiary points of regard (Figures
326 3A-C). For gaze frequency of the primary point of regard a segment-by-group interaction was found
327 ($F_{3,54}=3.4$, $P=0.02$, $\eta_p^2=0.16$) and a segment main effect ($F_{3,54}=2.8$, $P=0.05$, $\eta_p^2=0.13$) but not a group
328 main effect. For gaze frequency of the secondary point of regard only a group main effect was found
329 ($F_{1,18}=8.9$, $P=0.008$, $\eta_p^2=0.33$) with no segment main effect or segment-by-group main effect. There
330 were no gaze frequency interactions or main effects for the tertiary point of regard (Figures 4A-C).

331 **(Paragraph 27)** Group-by-trial-by-segment analysis for quaternary through to nonary points of regard
332 are excluded from this article for the sake of brevity, owing to the large amount of statistical data. We
333 also believe that the analysis of gaze data beyond the three most looked at points of regard are unlikely
334 to yield significant insights about systematic perceptual patterns, pacing and performance.

335 *Primary-Secondary Point of Regard Combinations*

336 **(Paragraph 28)** Data is presented in Table 2 shows the combination of primary and secondary points of
337 regard that participants looked at across the entire experimental time-trial and on a segment-by-segment
338 basis. Individual participant data is present in an attempt to convey the complex, yet in some instances
339 similar, patterns of information that participants looked at during the time-trial. Seven primary-
340 secondary point of regard combinations were observed for the novice group during TT_{EXP} , whereas the
341 experienced cyclists exhibited only three primary-secondary point of regard combinations.

342 **(Paragraph 29)** Mann-Whitney non-parametric comparisons were made between novices and
343 experienced cyclists in the number of primary points of regard they looked at in each segment and the
344 number of times they switched what they primarily looked at between segments. Results showed a lower
345 number of different primary points of regard by experienced cyclists compared to novices during TT_{EXP}

346 (1.7±0.8 vs. 2.8±0.9, U=19.5, Z=-2.41, P=0.008). From segment to segment, the number of times
347 participants switched to a different primary point of regard was lower among the experienced cyclists
348 compared to novices (1.3±1.4 vs. 2.3±0.9, U=31, Z=-1.53, P=0.064). Primary point of regard and switch
349 data is given in Table 2.

350 **(Paragraph 30)** A two-way mixed ANOVA found a group-by-segment interaction for the percent
351 dominance of the primary point of regard in the primary-secondary combination, $F_{3,54}=4.4$, $P=0.05$,
352 $\eta_p^2=.20$, a group main effect, $F_{1,18}=9.4$, $P=0.007$, $\eta_p^2=.34$, but no segment main effect, $F_{3,54}=0.4$, $P=0.52$,
353 $\eta_p^2=.02$. Independent-samples post-hoc t-tests revealed that dominance of the primary point of regard in
354 the primary-secondary combination was greater among experienced cyclists compared to novices for the
355 0-4 km segment (63.8±7.8% vs. 53.6±3.2%, $t_{18}=-3.8$, $P<0.001$, $\eta^2=0.45$), the 4-8 km segment
356 (61.7±8.0% vs. 56.2±4.3%, $t_{18}=-1.9$, $P=0.036$, $\eta^2=0.17$), the 8-12 km segment (63.4±6.5% vs.
357 56.6±5.3%, $t_{18}=-2.6$, $P=0.01$, $\eta^2=0.27$) but not the final 12-16.1 km segment (59.8±7.6% vs. 60.1±7.8%,
358 $t_{18}=0.1$, $P=0.93$, $\eta^2<0.01$). Group-by-trial-by-segment primary dominance values are given in Table 2.

359 **Discussion**

360 **(Paragraph 31)** This study was the first to make direct measurements of information-acquisition
361 behavior among time-trial cyclists and constitutes a significant step forward in our understanding of
362 endurance exercise pacing mechanisms. It seems that patterns of information acquisition during a self-
363 paced cycling time trials are very complex and that pacing behavior is not necessarily universally
364 informed by the integration of endpoint awareness and perceived exertion, as previous models have
365 argued (9,15,20,23,40,46,48,50). This is because we observed that, firstly, cyclists refer to different
366 types of information according to their experience, with experienced cyclists primarily looking at speed
367 and novices primarily looking at distance (Fig 2A). Secondly, experienced cyclists appear to be more
368 selective in their information acquisition behavior compared to novices, referring to fewer sources of

369 information, which they look at for longer (Fig 2A) and less frequently (Fig 2B). Thirdly, novices
370 increased the duration (Fig 3A) and frequency (Fig 4A) of looking at their primary information source
371 during the final segment of the time-trial but experienced cyclists were more constant throughout the
372 trials. Finally, with only four different combinations of primary and secondary information used by the
373 experienced cyclists, there was better commonality in what information they looked at compared to the
374 novices who used seven primary-secondary information combinations (Table 2). Our finding that
375 experienced cyclists refer to task-relevant information less often is consistent with a meta-analysis of
376 eye-tracking studies of expert performers (24), yet our findings that experienced cyclists fixate for longer
377 than novices is not consistent with the meta-analysis (24). This maybe because, as acknowledged by the
378 authors of the meta-analysis, the type of sport task may moderate expert-novice differences in visual
379 behavior compared to other domains (24). Experienced cyclists also tended to stick to a primary
380 information source throughout the time-trial, whereas novices switched the type of information they
381 primarily looked at between segments much more often (Table 2). We are not suggesting that endpoint
382 awareness is not important in pacing regulation, clearly it is given how often it featured as either a
383 primary or secondary point of regard in our findings (Table 2). Our argument is that previous pacing
384 models are deficient in accounting for variations in information acquisition that we have found
385 attributable to individual preference, expertise or event segment. It seems that in simulated time-trial
386 cycling experienced cyclists look at speed more than distance, whereas distance feedback appears to be
387 what novices seek out more.

388 **(Paragraph 32)** An important finding of this study was that experienced and novice cyclists differed in
389 the types of information they looked at during the experimental time trial. The majority of the
390 experienced cyclists (9 of 10 participants) tended to look at speed most across the whole time trial. In
391 contrast most novices (6 of 10 participants) looked at distance most, noting that a significant number of

392 novices (4 of 10 participants) chose to primarily look at other information too. In addition to experienced
393 cyclists being more consistent in what information they look at, of note is that they looked at primary
394 information for longer and less frequently.

395 **(Paragraph 33)** While the eye-tracking data we have collected reveals a lot about how time-trial cyclists
396 acquire information, it does not tell us anything about how the information is integrated and processed,
397 or the decisions they have made. For this, other process-tracing methods such as think aloud protocols,
398 may usefully compliment eye-tracking in the study of decision-making and pacing. This is because that,
399 while eye-tracking technology provides a powerful method for measure information acquisition
400 processes, it reveals nothing about how that information is subsequently processed. Although longer eye
401 fixation times have been linked to greater depth of processing (16,26,43,44), rather than assuming this to
402 be the case in future pacing studies, it would be preferable to use eye-tracking in conjunction with think
403 aloud protocols to directly capture information processes. Nevertheless, the results of the present study
404 so highlight differences in information acquisition between novice and experienced time-trial cyclists
405 that bring to question the common information-processing mechanisms put forward by previous pacing
406 models (9,15,18,23,31,34,40,42,45,50). In particular, the assumption in previous pacing models that the
407 integration of endpoint awareness with perceived exertion is the primary and universal driver of pacing
408 decisions, regardless of athletic experience or individual feedback preferences. It may be that decision-
409 making among experienced cyclists was different to novices and indeed different between individuals
410 which resulted in a need to seek out more varied sources of information. This is consistent with the idea
411 that individuals use information in an adaptive way according to the perceived demands of a situation or
412 problem (25). Thus, it could be that distance information is still important to experienced cyclists but,
413 owing to their previous experience, they are able to process and integrate such information much more
414 quickly and thus do not need to look at it quite so often or for so long. Since the experienced participants

415 were experienced at performing the 16.1 km time-trial format, it is also quite likely that their need to
416 refer to distance information was less than novices unaccustomed to cycling such a distance. The extent
417 to which information acquisition differences between experienced and novice cyclists are attributable to
418 distance familiarity, is something that could be tested by using the same experimental protocol but with
419 an unfamiliar time trial distance. While it is well established that experience influences pacing strategy
420 (19,35,38), our findings further show that information acquisition strategies accompanying pacing
421 behavior also vary with previous experience.

422 **(Paragraph 34)** As expected the experienced cyclists completed both time-trials faster than the novices,
423 with both groups exhibiting a mostly constant pace throughout. Owing to imperfect fitness matching
424 between the novice and experienced cyclists, we cannot conclude that that time-trial performance
425 differences between the groups was exclusively due to experience differences. While in future studies
426 greater effort should be made to measure associations between moment-by-moment change in gaze and
427 pacing time-series data (37), in this study we have limited our analysis to detecting concomitant changes
428 in gaze and pace at a segment-by-segment level. What our data clearly shows is that, whatever type of
429 information is preferred as the primary reference, the experienced cyclists looked at it for longer than the
430 novices but less frequently. As previously discussed, this is broadly consistent with previous expertise
431 literature (24). During the second time-trial the experienced cyclists increased the relative amount of
432 time they spent looking at the primary information source from 30 to 35% showing that they became
433 more selective in what information they referred to. The shallower curves presented in Figure 2A also
434 shows that novices tended to distribute their attention across a number of different information sources,
435 spending more time looking at quaternary to octonary sources of information compared to the
436 experienced cyclists. The notion that experienced cyclists are more selective in what feedback they look
437 at is also consistent with previous expertise literature (24,33) and is supported in a number of ways. In

438 the first three segments, the experienced cyclists on average spent between 5-10% longer than novices
439 looking at the primary point of regard. It was only in the last segment of the time-trials from 12-16.1 km,
440 that the novices increase both the amount of time and the frequency with which they look at the primary
441 information source close to that of the experienced cyclists. The increased information acquisition
442 behavior towards the end of the time-trial is consistent with the behavior observed in children during a
443 self-paced running task (6), further supporting the idea that feedback-dependency is more strongly
444 associated with proximity to the end-point among inexperienced athletes compared to experienced
445 athletes.

446 **(Paragraph 35)** The data from our study indicates greater consistency in experienced cyclists' approach
447 to information acquisition both in terms in inter- and intra-participant behavior. Inter-participant
448 consistency is evident in the data showing that 9 of 10 experienced cyclists chose to primarily look at
449 speed. Even when combinations of information sources are considered, experienced cyclists consistency
450 chose either speed-distance (5/10), speed-other (2/10) or speed-power (2/10) as the combination of
451 primary and secondary points of regard. In fact, the experienced cyclists only exhibited four different
452 primary-secondary information combinations, whereas seven different primary-secondary combinations
453 were observed among the novices (Table 2).

454 **(Paragraph 36)** Greater intra-participant consistency among the experienced cyclists is apparent owing
455 to the fact that on a segment-by-segment basis, the modal primary-secondary combinations were speed-
456 distance and speed other, but for the novices it was often not possible to specify a modal combination
457 because the primary-secondary permutations were so varied. On average novices used 2.3 different
458 primary information sources across the four segments compared to 1.5 for the experienced cyclists.
459 Novices also tended to switch primary information sources between segments more frequently than the
460 experienced cyclists as indicated in Table 2.

461 **(Paragraph 37)** The primary-secondary combination data presented in Table 2 is also interesting
462 because it highlights that distance is still an important reference source to experienced cyclists, but only
463 secondary to and in combination with speed. In contrast, distance feedback appears to be the most
464 dominant type of information they refer to in combination with many other types of secondary
465 information. A lot of emphasis has been placed the role of the endpoint in influencing pacing
466 (2,3,9,15,19,31,34,40,46,50) support for which being found in a number of studies where deception or
467 blinding methods have been used (3,12,30,38). However, our study shows that the importance placed on
468 knowledge of the end-point may be overstated in most pacing models and that, knowledge of the
469 endpoint may in fact be a secondary to information about speed in informing the actions of experienced
470 cyclists. Another interesting outcome of this study is that perceived exertion did not feature in the
471 primary-secondary information acquisition combinations for any of the participants (Table 2), and that,
472 whether experienced or novice cyclists, all looked at least three other sources of information in
473 preference to the 6-20 RPE scale (Fig 2). That does not mean perceived exertion is not an important
474 factor in pacing decisions as predicted by many of the previous models. It does however, highlight to
475 methodological complexities of investigating pacing decisions in terms of the acquisition and utilization
476 of external referents, which can be easily observed using methods like eye-tracking, and the integration
477 of internal bodily referents such as perceived exertion, which cannot be directly observed. This particular
478 problem warrants innovative research using process-tracing methods of the kind described in much more
479 detail elsewhere (37).

480 **(Paragraph 38)** This eye-tracking study has produced some important new data not entirely consistent
481 with previous models of pacing about the attention to, and use of, feedback information. Nevertheless,
482 there are a number of limitations associated with the laboratory-based nature of this experiment and the
483 eye-tracking technology that was used. Cyclists in our study performed simulated time-trials on a static

484 cycle ergometer under conditions where certain demands on the visual system were absent, for example
485 those associated with balancing, navigating, negotiating hazards and avoiding collisions as reported
486 elsewhere (51, 53). Furthermore, differences between laboratory and real-world visual behavior have
487 been reported in several studies, the most notable findings being more centralized fixations in the real
488 world (17), a tendency to fixate on closer objects in the laboratory (17), and earlier longer object
489 fixations in the realworld (10). Therefore, it cannot be assumed that, during road-based time-trials, the
490 capacity to attend to performance information will be the same as reported in this experiment since it
491 will compete with, or be interrupted by, other demands placed on the visual system. In the future, with
492 careful configuration of mobile eye-tracking technology, it may be possible to measure the attention to
493 performance information in field-based studies with associated improvements in ecological validity.

494 **(Paragraph 39)** Another limitation of this study relates to the link between visual information, decision-
495 making processes and pacing behavior. While there is some evidence that what individuals look at is
496 associated with their choices (16,26,43,44), it is unclear whether visual attention influences choice or
497 simply reflects a choice that has been made (44). In our study the issue is further complicated by the
498 difficulties of quantifying a pacing choice, since the method of detecting a meaningful change in pace
499 from either speed or power time-series data is mathematically complex (41). Even if it were possible to
500 precisely identify moments where a decision had been made to increase or decrease pace, decisions to
501 maintain pace would clearly be impossible to detect, as they would not be indirectly reflected in time-
502 series data. In this study, conclusions about the link between visual attention and pacing decisions, are
503 deduced from the associated changes in vision and pace observed at a segment-by-segment level. In
504 future, greater precision about the association between visual attention to performance information and
505 pace could be investigated by setting up experiments were cyclists are presented with pacing dilemma
506 where their decision to act can be pinpointed in time.

507 **(Paragraph 40)** Finally, with regards to information acquisition and decision-making during endurance
508 sport, further consideration is needed regarding fatigue related constraints on visual behavior as
509 predicted in Newell's model (39) because they are often overlooked (56). A relationship between fatigue
510 and declining visual attention was found in one interesting study where increased levels of exertion
511 among biathletes was associated with reduced visual behavior before making a rifle shot (54). Saccadic
512 eye-movements are so fast and energetically efficient (47) that they are less likely to be responsible for
513 such effects compared to high-order cognitive processes such as attention allocation mechanisms which
514 have themselves been found to become fatigued as characterized by reduced capability to suppress
515 irrelevant external cues (13). Such factors are likely to impact information acquisition and decision-
516 making during endurance sport and warrant further investigation.

517 **Conclusions**

518 **(Paragraph 41)** Although perhaps counterintuitive, this study challenges the degree of importance
519 placed on knowledge of the endpoint to pacing in previous models. This is especially true for
520 experienced cyclists for whom distance feedback was looked at secondary to, but in conjunction with
521 information about speed. Novice cyclists appear to have a greater dependence upon distance feedback,
522 which they look at for shorter and more frequent periods of time than the experienced cyclists.
523 Experienced cyclists are more selective in the information they refer to during a time-trial and they are
524 also more consistent in the combination of primary and secondary information they use, and more
525 consistent between various phases of a time-trial. The difference in information acquisition behavior
526 observed in this study may reflect differences in motivational regulators, with experienced cyclists
527 perhaps focusing more strongly on performing at the fastest speed and novices focusing on completion
528 of the distance.

529 **(Paragraph 42)** This study is the first to directly measure cyclists' information acquisition behavior
530 during a time-trial and the data shows that the information athletes attend to and use during self-paced
531 endurance tasks is much more complex than previously assumed and not necessarily dominated by
532 knowledge of the endpoint. The limitations associated with this study are that it cannot be assumed
533 information acquisition would be the same during a road-based time-trial. There are also improvements
534 to the analysis of time-series performance data that are needed to reveal hidden moments where a
535 decision to alter pace has been made so that corresponding gaze behavior can be interrogated with
536 greater precision. Nevertheless, this study has produced some exciting new insights about the
537 information acquisition strategies of experienced and novice cyclists, as well as a new method for
538 investigating visual attention and decision-making during paced exercise.

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Figure Legends

Figure 1. Overall time-trial performance (A) and time-trial pacing by segment for familiarization (B) and time-trial 1 (C).

Figure 2. Novice and Experienced total gaze duration data (A) and average gaze frequency (B) for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance for time-trial 1 (A) The type of information looked at with the corresponding number of subjects is presented alongside the data points in 2A for primary to tertiary sources but not included for quaternary to nonary sources. * denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$.

Figure 3. Experienced versus novice segment-by-segment time-trial 1 total gaze duration data for primary (A), secondary (B) and tertiary information sources (C). * Denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$; NS denotes not significant.

Figure 4. Experienced versus novice segment-by-segment time-trial 1 average gaze frequency for primary (A), secondary (B) and tertiary information sources (C). * Denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$; NS denotes not significant.

Table 1. Mean performance, heart rate and RPE time-trial data for group, trial and segment

		0-4 km		4-8 km		8-12 km		12-16.1 km		Overall	
		Novice	Experience	Novice	Experience	Novice	Experience	Novice	Experience	Novice	Experience
Speed (km/hr)	TT _{FAM}	31.2(2.7)	34.9(1.8) _{NS}	31.3(3.2)	34.4(1.8) _{NS}	31.3(3.3)	34.2(1.5) _{NS}	32.2(2.3)	34.5(1.5) _{NS}	31.5(2.8)	34.5(1.5) _{NS}
	TT _{EXP}	31.8(2.6)	34.9(1.8) _{NS}	32.0(2.8)	34.8(1.9) _{NS}	32.0(2.4)	34.6(2) _{NS}	32.6(3.1)	35.2(1.9) _{NS}	32.1(2.7)	34.9(1.8) _{NS}
Completion Time (s)	TT _{FAM}	465(45)	413(21) _{NS}	464(57)	418(22) _{NS}	465(59)	421(19) _{NS}	459(38)	426(18) _{NS}	1854(193)	1680(75) _{NS}
	TT _{EXP}	455(42)	413(21) _{NS}	452(45)	414(23) _{NS}	452(37)	416(25) _{NS}	455(52)	419(23) _{NS}	1816(176)	1663(90) _{NS}
Power (W)	TT _{FAM}	201(42)	261(39) _{NS}	200(46)	256(38) _{NS}	200(48)	257(27) _{NS}	214(38)	267(23) _{NS}	204(42)	260(30) _{NS}
	TT _{EXP}	210(41)	272(29) _{NS}	212(44)	265(34) _{NS}	210(38)	263(28) _{NS}	223(46)	272(32) _{NS}	214(42)	268(29) _{NS}
Cadence (rpm)	TT _{FAM}	85(10)	97(5) _{NS}	86(11)	98(4) _{NS}	86(12)	104(17) _{NS}	89(10)	96(2) _{NS}	86(11)	99(3)
	TT _{EXP}	77(17)	95(8) _{NS}	85(11)	95(7) _{NS}	86(11)	96(6) _{NS}	88(11)	96(7) _{NS}	84(9)	96(7)
Heart Rate (bpm)	TT _{FAM}	146(19)	148(19)	160(17)	163(15)	166(17)	166(14)	176(13)	171(12)	162(16)	162(15)
	TT _{EXP}	139(12)	145(12)	161(11)	162(14)	169(7)	162(26)	175(6)	172(17)	161(7)	160(16)
RPE	TT _{FAM}	12.9(0.7)	13.5(1.1)	14.6(0.6)	15.1(1.1)	16.2(0.9)	16.3(1.2)	18.7(0.8)	18.6(0.9)	15.6(0.6)	15.8(1.0)
	TT _{EXP}	13.0(0.9)	13.3(1.1)	15.0(1.3)	14.8(1.3)	16.2(1.3)	17.1(1.4)	18.9(0.9)	18.9(0.8)	15.7(1.0)	16.0(1.0)

Note: Post hoc-tests are only indicated where significant ANOVA interactions or main effects were found. NS - Not significant; *P<0.05; **P<0.01; ***P<0.001.

Table 2. Individual gaze combinations of primary and secondary information sources.

ID	Primary-Secondary Combination for the Whole Time-Trial	*Group Code	Primary-Secondary Combination Change by Segment (4-8-12-16 km)	**Primary Dominance by Segment (%)	Different Primary Sources Used per Segment (N)	Primary Source Switches Between Segments (N)
Novices						
S13	DS		SD-DS-DS-PD	52-59-55-62	3	2
S3	DS	1	DT-DP-DS-DS	50-56-57-54	1	0
S8	DS		OV-DS-TS-DT	58-53-51-65	3	3
S10	DO	2	CD-HD-OD-DO	50-51-51-51	4	3
S11	DO		DO-DP-DO-DO	51-65-64-61	1	0
S12	DP	3	DP-DP-PD-DT	58-53-56-78	2	2
S7	PD	4	DV-PT-PS-DS	55-60-60-60	2	2
S9	SD	5	SD-SD-SO-SD	56-52-55-52	1	0
S6	VD	6	DP-VO-VO-DO	55-57-66-56	2	2
S1	TP	7	OT-PV-TP-DV	51-56-51-62	4	3
Mean				54-56-57-60	2.3	1.7
S.D.				3-4-5-8	1.2	1.3
Mode	DS		##-##-##-DO		1	2
Experts						
S24	SD		SD-SD-SD-SD	61-62-64-64	1	0
S25	SD		SP-SD-OD-SH	50-50-52-52	2	2
S26	SD	5	DS-DS-SD-SD	54-52-62-71	2	1
S30	SD		SO-SO-SD-SO	66-62-58-61	1	0
S32	SD		SD-SO-SO-SD	64-64-70-66	1	0
S22	SO	8	SD-ST-OS-SO	78-79-59-53	2	2
S27	SO		SD-SO-SO-SD	69-57-70-59	1	0
S21	SP	9	SP-SO-SP-DS	65-65-72-51	2	1
S28	SP		SP-SP-SO-SP	68-61-68-69	1	0
S23	PS	10	PS-PS-PD-SH	63-65-59-52	2	1
Mean				64-62-63-60	1.5	0.7
S.D.				8-8-7-8	0.5	0.8
Mode	SD		##-SO-SO-SD		1	0

Note - *Group code represents a specific combination of primary-secondary point of regard; **Dominance of the primary point of regard is expressed as a percentage of the combined gaze time for both primary and secondary points of regard. Primary-secondary point of regard combinations are represented by two letters, with each single letter being coded as follows: S=Speed; D=Elapsed Distance; P=Power; C=Cadence; H=Heart Rate; T=Elapsed Time; R=Rating of Perceived Exertion; V=Projector Simulation View and O=Other. ## Indicating mode shared by more than one category

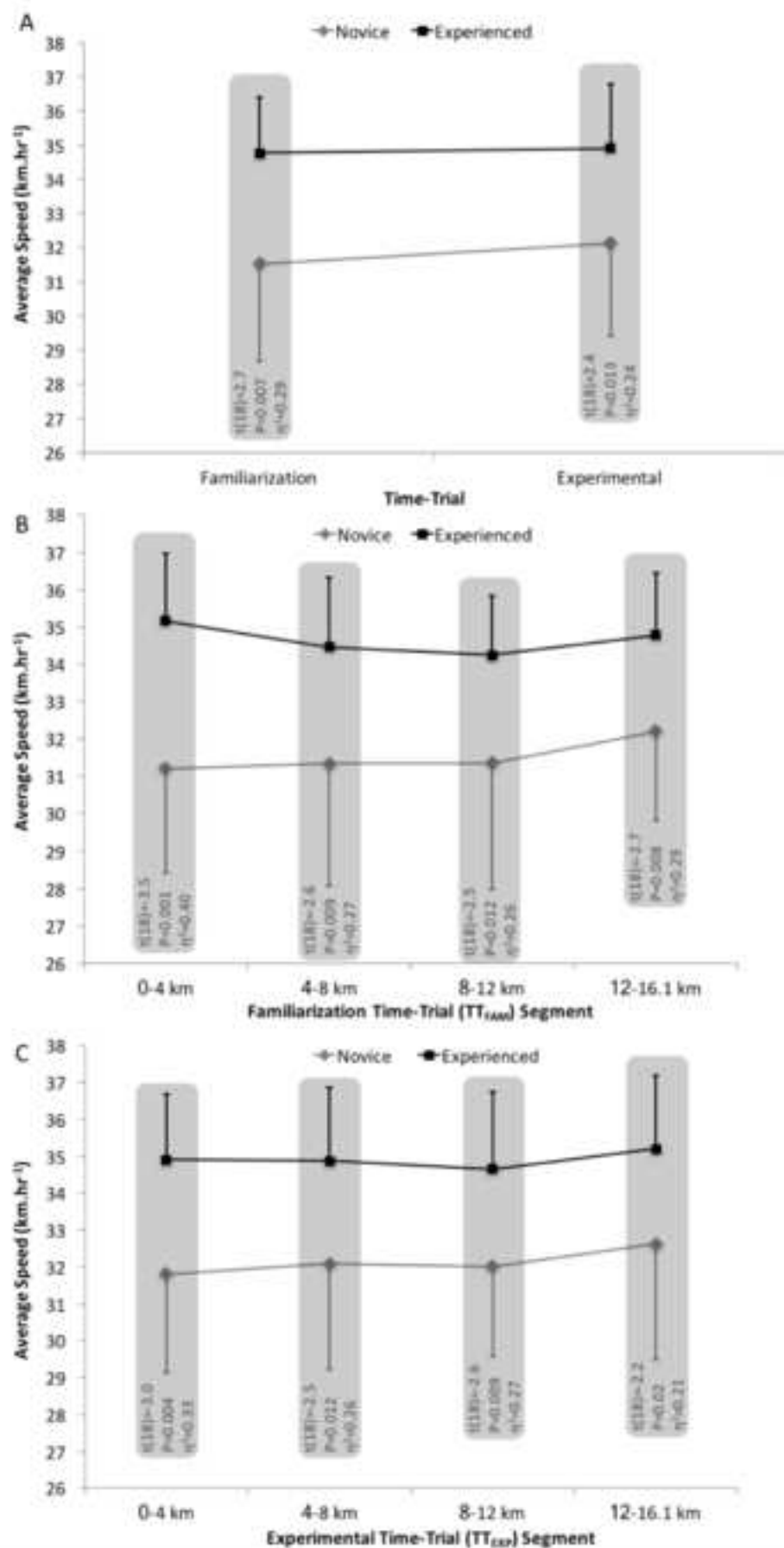


Figure 1. Overall time-trial performance (A) and time-trial pacing by segment for familiarization (B) and time-trial 1 (C).

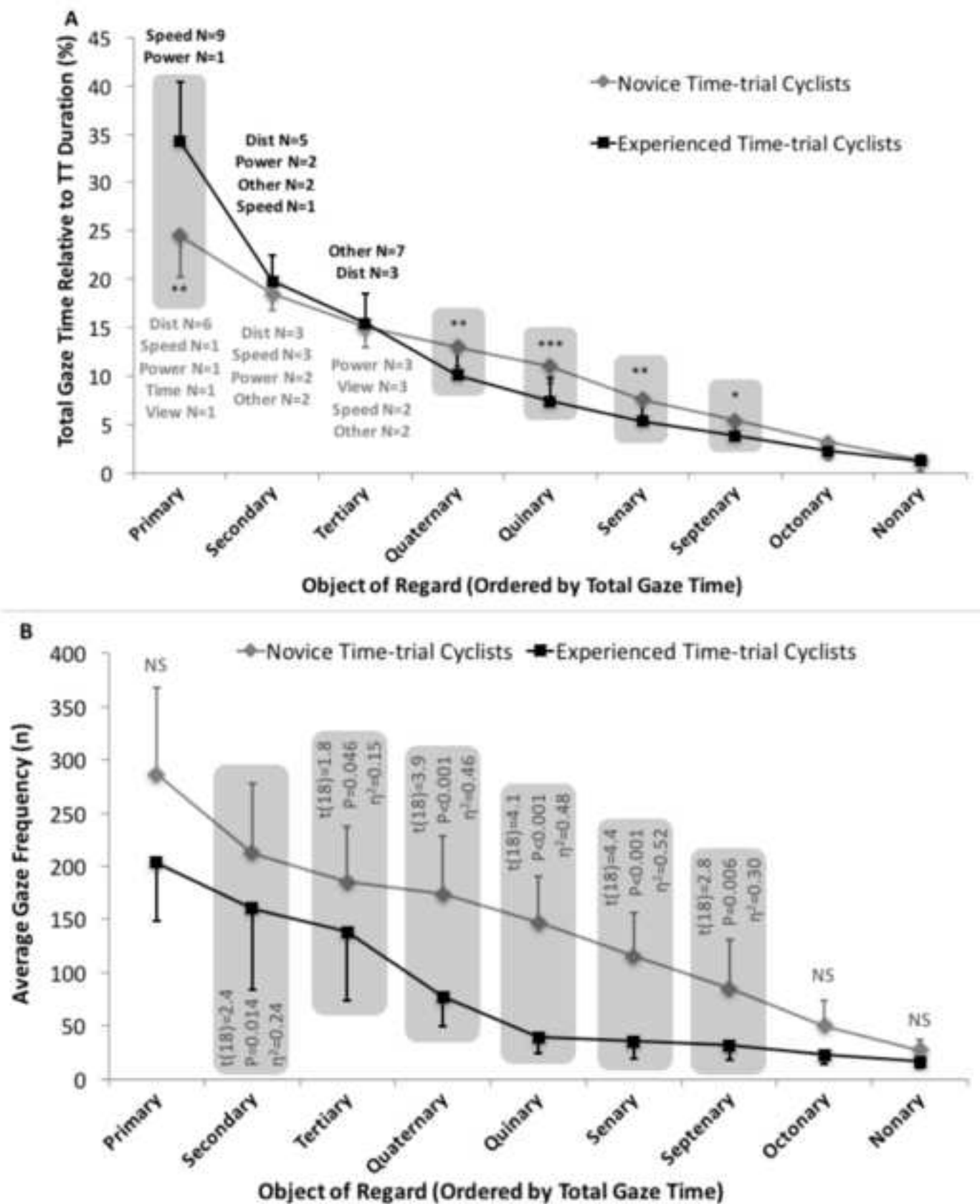


Figure 2. Novice and Expert total gaze duration data (A) and average gaze frequency (B) for primary (most looked at) through to nonary (least looked at) information sources calculated over the full 16.1 km distance for time-trial 1 (A) The type of information looked at with the corresponding number of subjects is presented alongside the data points in 2A for primary to tertiary sources but not included for quaternary to nonary sources. * denotes $P<0.05$; ** denotes $P<0.01$; *** denotes $P<0.001$.

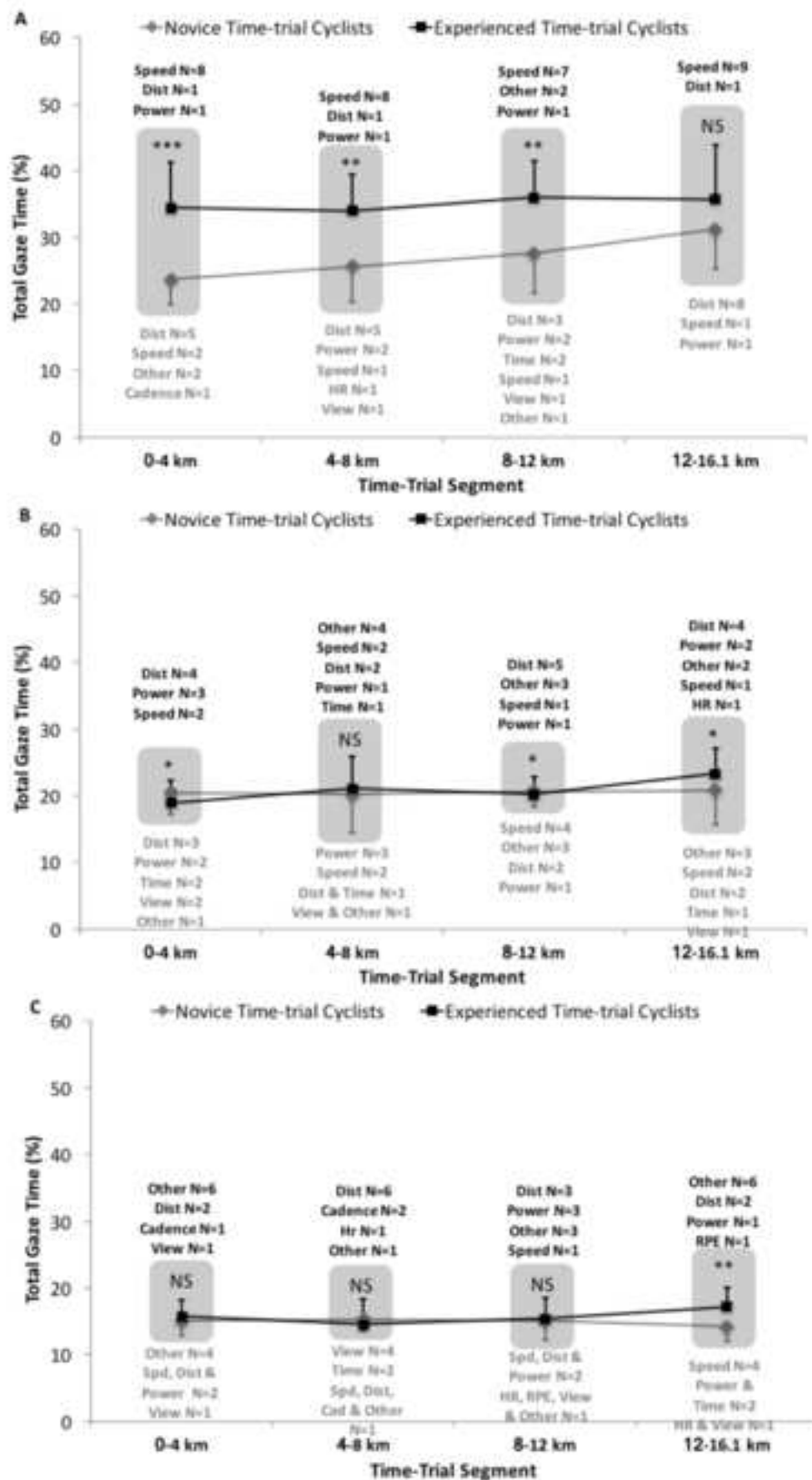


Figure 3. Expert versus novice segment-by-segment time-trial 1 total gaze duration data for primary (A), secondary (B) and tertiary information sources (C). * Denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$; NS denotes not significant.

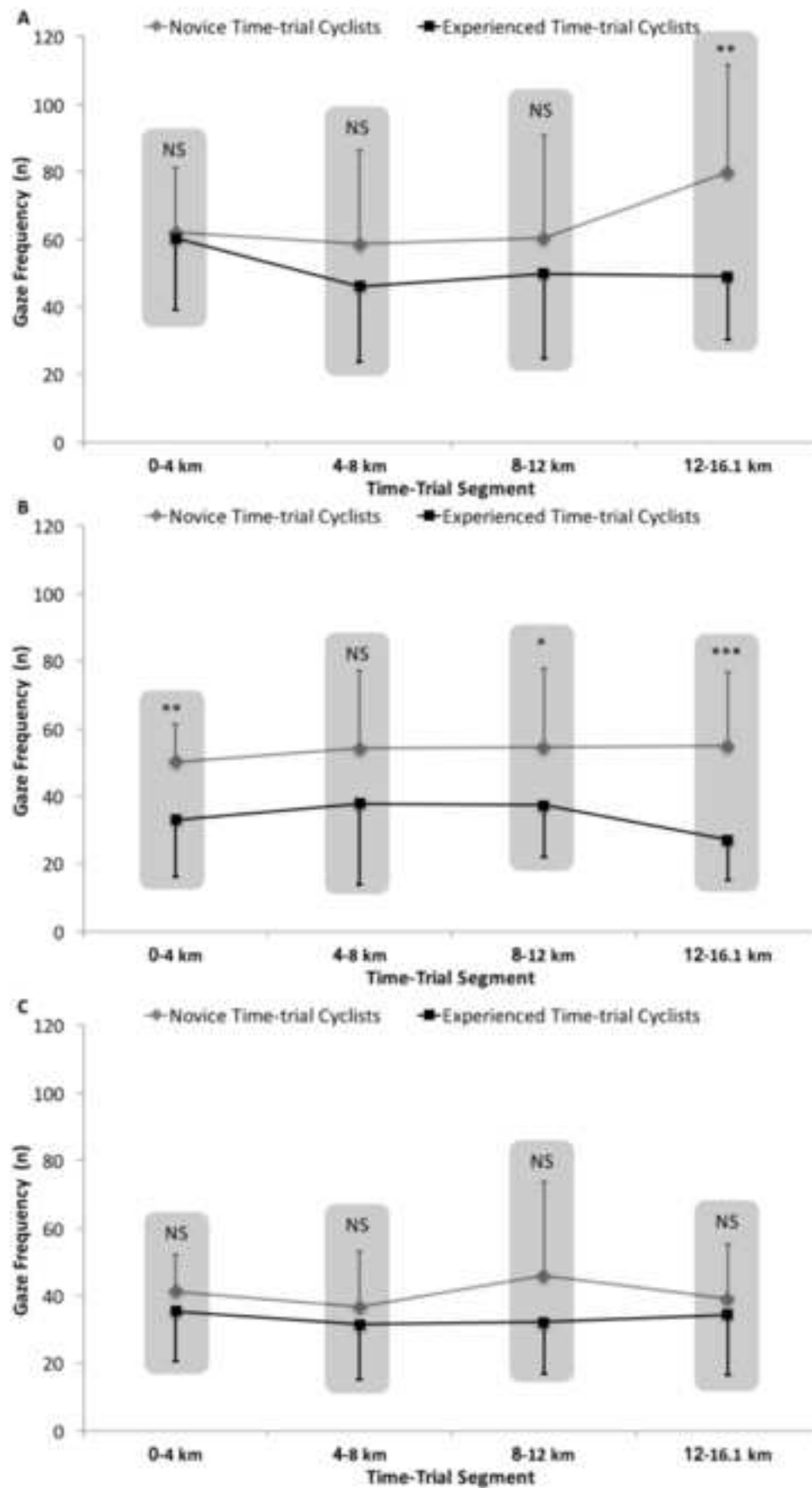


Figure 4. Expert versus novice segment-by-segment time-trial 1 average gaze frequency for primary (A), secondary (B) and tertiary information sources (C). * Denotes $P < 0.05$; ** denotes $P < 0.01$; *** denotes $P < 0.001$; NS denotes not significant.