ABBREVIATED TITLE PAGE:

INCREASING NAVIGATION SPEED AT ENDOLUMINAL CT COLONOGRAPHY REDUCES COLONIC VISUALISATION AND POLYP IDENTIFICATION

MANUSCRIPT TYPE: Original Research

ADVANCES IN KNOWLEDGE:

1. As fly-through speed increases beyond 1cm/s, reader gaze progressively narrows, reaching <3% time spent looking at the periphery of the image at higher speeds; "tunnel vision".
2. Increasing fly-though speed is accompanied by a reduction in true-positive polyp identifications, from 72% at 1cm/s to 61% at 4.5cm/s (p=0.004).
3. False-positive polyp identifications also fall at higher speeds (37% at 1cm/s, 26% at 4.5cm/s, p=0.02).

IMPLICATIONS FOR PATIENT CARE:

1. Radiologists should avoid pressures to interpret large numbers of CTC examinations rapidly as this is likely to provoke incomplete luminal visualization and reduce polyp detection.
2. CTC workstations may benefit from software to monitor and display endoluminal navigation speed.

SUMMARY STATEMENT:

As navigation speed increases, readers' gaze becomes more central and polyp identification rates fall.

ABSTRACT:

Purpose: To investigate the effect of increasing navigation speed on (a) readers' visual search and (b) decision-making during polyp identification for CT colonography (CTC).

Methods: Ethical permission was granted for this prospective study. Following informed consent, twelve CTC fly-through examinations (depicting 8 polyps) were presented at four different fixed navigation speeds to 23 radiologists. Speeds ranged from 1cm/s to 4.5cm/s. Gaze position was tracked using an infra-red eye-tracker, and readers indicated seeing a polyp by clicking a mouse. Patterns of search and decision-making by speed were investigated graphically and by multi-level modelling.

Results: Readers identified polyps correctly in 73% of viewings at the slowest speed but only 61% of viewings at the fastest (p=0.004). They also identified fewer false positive features at faster speeds (37% of videos at slowest speed, 26% at fastest, p=0.02). Gaze location was highly concentrated towards the central quarter of the screen area at faster speeds (mean 86% of gaze points at slowest speed, 97% at fastest speed).

Conclusions: Faster navigation speed at endoluminal CTC leads to progressive restriction of visual search patterns. Greater speed also reduces both true-positive and false-positive colorectal polyp identification.

KEYWORDS:

Colonography, Computed Tomographic; Visual search; Gaze tracking; Visual perception; Colorectal polyps

Introduction

CT colonography (CTC) has been widely adopted internationally since its original description in 1994 because it is sensitive for colorectal cancer and polyps, well-tolerated, safe and relatively inexpensive[1,2]. Competent interpretation requires both 2-dimensional (2D) and 3-dimensional (3D) image display, although relative contribution varies by radiologist preference. Interpretation is time-consuming, particularly for 3D interpretation[3,4]; prolonged interpretation time will reduce the number of studies interpreted per working day. Radiologists are increasingly under pressure to maximize reading speed to accommodate service demand, in both screening and symptomatic practice.

CTC interpretation software permits the reader to vary the speed at which the volume-rendered viewpoint (i.e. the "virtual colonoscope") progresses along the colonic centreline. Clearly, faster navigation lessens time taken to traverse the colon, but individual radiologists' preferred speeds for colonic navigation are unknown, as is the effect of increasing speed on diagnostic accuracy, if any. When interpreting 2D images such as chest[5] or bone[6] radiographs, radiologists are capable of high sensitivity even at considerably reduced viewing times – as low as 4 seconds for pulmonary nodule detection at chest radiography in one study[7]. It is therefore plausible that radiologists could increase CTC navigation speed without compromising diagnostic performance. However, this is speculative – what is true for interpretation of static 2D radiographs may not apply to moving 3D images, where pathology changes in shape, size and position. The effect of faster velocities on visual interrogation and detection of colorectal polyps is unknown currently. Eye-tracking technology, whereby gaze is monitored during interpretation, can document and quantify these parameters[8], since it permits the study of both diagnostic decision-making and the nature of image visual interrogation simultaneously.

By eye-tracking radiologists during interpretation, we aimed to investigate the effect of increasing navigation speed on (a) readers' visual search and (b) decision-making during polyp identification for CT colonography (CTC).

Materials and Methods

Permissions

Ethical approval was granted by the (BLINDED) committee (project ID:) for this prospective study. Anonymised CTC images were derived from Institutional Review Board and Research Ethics Committee-approved studies[9,10].

CTC data sets and video generation

CTC data from 112 patients (symptomatic:11; screening:101) were collated from three US and two European centres between Jan 2002 and June 2005. A reference standard for the presence and location of polyps in these patients was established in consensus by three radiologists (including S.A.T. and S.H., each with experience of over 1000 CTC cases and over 10 years), each of whom read each dataset twice, assisted by colonoscopy reports[10]. From this validated case-set, following a suitable power calculation (see below) a selection of 12 fly-through videos was generated using a commercially-available CTC workstation (Vitrea, Vital Images, Minnesota, USA). Examinations had been acquired on a 16-row MDCT unit (GE Lightspeed Plus or Ultra) using a slice thickness of 1.5-3mm, a reconstruction interval of 1mm, variable mAs (50-100mAs) and 120kVp. Patients received oral contrast tagging but no intravenous contrast.

8 true-positive cases (P1-P8, each depicting a single 5-8mm polyp) and 4 true-negative cases (N1-N4) were selected. For each of these 12 cases, an image perception scientist (P.J.P.) produced 4 videos that were identical other than having different navigation speeds along the colonic centreline. For each case, a source video was exported from the CTC workstation and fixed colonic landmarks (e.g. diverticula or polyps) identified subsequently. An experienced colonographer (A.A.P, >1000 cases and >8years experience of CTC) then measured the distance along the colonic centreline between these fixed landmarks. This distance was then used to establish navigation speed during standard playback in centimeters/second (cm/s). This was then adjusted to achieve navigation speeds of 1 cm/s, 1.5 cm/s, 3 cm/s and 4.5 cm/s (Speeds 1 to 4 respectively). These speeds were selected after discussion with several CTC experts and following a pilot experiment using 5 volunteers, to confirm that the videos spanned a plausible range of CTC interpretation speeds.

Eye tracking procedure

Piloting showed that viewing longer than 25 minutes or more than 40 videos was fatiguing. We therefore randomly selected 40 videos for each reader using block randomization (5 blocks of 8 videos). Within each block, one video was at Speed 1, one was at Speed 2, and there were 3 videos each for Speeds 3 and 4. This structure imposed an adequate mix of differing speeds and maximised the total number of video viewings (as faster speeds require less time to view) while constraining the experiment within approximately 25 minutes. Thus, the 40 viewings undertaken by each reader were drawn from the same set of videos, but the mix of speeds per video differed between readers. Randomization was performed separately for each reader using the *sample* command in R version 3.0.1 (R Foundation for Statistical Computing, Vienna, Austria)[11].

Viewing was conducted in a quiet area at the European Society of Gastrointestinal and Abdominal Radiology (ESGAR) CTC Training Workshop, Leeds, 2014, using the central 512x512 pixels of a 1280x1024 pixel thin film transistor (TFT) monitor (ProLite B1902S, Iiyama) with a 4:3 aspect ratio and 19-inch diagonal display. Ambient light levels were not measured formally, but were held constant during the experiments and were similar subjectively to a radiology reporting room, with no external natural daylight. During case viewing, a Tobii X120 infra-red eye-tracker (Tobii technology, Stockholm, Sweden) was used to monitor pupil movements. The device is a small set of sensors that can be positioned beneath a normal monitor. Readers were asked to indicate when they had detected a polyp (not the polyp's location), and received the following instructions prior to case viewing:

"You are about to see some videos of CTC endoluminal "fly-through" examinations, some of which have polyps. These will be displayed at different speeds. Please click your mouse when you see a lesion that you think is highly likely to be a real polyp or cancer."

Prior to eye-tracking, we recorded readers' preferred navigation speeds, both before and after the main experiment. A further CTC video was displayed at a known, but user-controllable velocity, and participants were invited to set the video playback to their normal clinical interpretation speed.

Power and sample size

Sample size was estimated by simulation to allow for the cross-classified nature of the design, using variance estimates from a previous study.[12] A sample of 25 readers, each viewing 4 videos at Speed 1 and 10 at Speed 4, had 80% power to detect a reduction in true-positive polyp identifications from

60% (Speed 1) to 40% (Speed 4) at 5% level of significance; and 90% power to detect a reduction from 60% (Speed 1) to 35% (Speed 4). To prevent underpowering due to under-recruitment, ultimately we raised the number of case viewings to 5 at each of Speeds 1 and 2 and 15 at each of Speeds 3 and 4 (yielding the 40 videos/reader as per above).

Participants

All participants provided written informed consent. We recruited experienced (>2 years' experience of CTC and >300 total case experience, including >100 cases in the preceding 12 months, n=13) and inexperienced (not meeting these criteria; all <200 cases experience, n=10) radiologists. We recorded participant age, sex, clinical seniority/grade, prior experience of CTC (years and cases), prior radiological experience in years, preferred CTC reading strategy (2D vs 3D), and number of CTC interpreted in the preceding 12 months.

Post-processing and analysis of eye-tracking data

To determine if readers' gaze pursued a polyp, we followed a procedure similar to published experiments[8,12-14]. In brief, a visual perception scientist (P.J.P., 8 years experience of handling eye-tracking data) assisted by a radiologist (A.A.P., 4 years experience of eye-tracking and 8 years experience of CTC) in consensus outlined the approximate boundary of individual polyps with a spherical region of interest (ROI). We defined eye pursuit of a polyp as occurring when readers' gaze fell within 50 pixels of this polyp boundary for a continuous period of 100ms or more. Eye pursuits were analysed as: (1) the presence of at least one pursuit during viewing of a video; (2) the number of pursuits during viewing of a video and (3) the rate of pursuits per second of video display. Total pursuit time was defined as the proportion of the total time the polyp was on the screen during which eye pursuit of that polyp occurred. Time to first pursuit was defined as the proportion of this time that had elapsed before the first eye pursuit occurred.

We treated all mouse clicks while the polyp was displayed on screen (plus a 500ms subsequent window for reaction time) as representing true-positive polyp identifications. All mouse clicks occurring before the polyp was displayed on screen were treated as false-positive identifications. Mouse clicks occurring more than 500ms after the polyp had disappeared from the screen were ignored, as we could not distinguish with certainty whether these were false-positive polyp identifications or delayed but correct clicks after a longer period of reader consideration. We also

conducted a sensitivity analysis in which these clicks were regarded as false-positives, which inspection of the eye-tracking data showed was the more plausible of the two scenarios.

We also measured reader eye gaze distribution during video interpretation by dividing the 512x512 pixel video size into two areas; (a) a 256x256 pixel central square (25% total video area) and (b) the peripheral 75% beyond this; the periphery was subdivided further into equal upper and lower halves.

Statistical analysis

Data were collated using Microsoft Excel (Microsoft Corp, Redmond, WA, USA) and analysed using Stata v14.0 (Statacorp, College Station, TX, USA) and R v3.2.4. The effect of navigation speed along the colonic centreline on polyp identification and eye tracking metrics were tested using multilevel regression modelling (a maximum likelihood method), with independent random terms for reader and case to allow for clustering, including speed as a fixed factor variable, and adjusting for reader level of experience.

Short runs of missing eye-tracking data were imputed using the immediate preceding and following eye coordinates, with the addition of random measurement error. Summary estimates were then pooled using multiple imputation methods[15] with ten imputations. A small number of cases (n=18/920, 2%) with either more than 50% missing data values in total or more than 50 consecutive missing values (100 missing values for the screen coverage metric) were regarded as unreliable, and excluded.

Results are expressed relative to Speed 1 (1.0cm/s, slowest) as the reference category. A sensitivity analysis included an interaction term between speed and level of experience. Effect sizes were summarized using odds ratios or rate ratios as appropriate, with 95% confidence intervals; p-values <0.05 were taken to be statistically-significant.

Results

23 readers participated (18 male, mean age 40 years, range 30 to 63 years). Experienced readers (n=13) had an average of 10 years of experience using CTC.

Preferred navigation speed

The average (SD) preferred navigation speed was 1.18 (0.52)cm/s at the start of the experiment, with no significant difference between experienced and inexperienced readers (experienced:1.22 cm/s; inexperienced:1.12 cm/s; 95%CI 0.53 to -0.33 cm/s, p=0.62). After case viewing was completed, preferred speed was similar, at 1.18 (0.39)cm/s (experienced:1.13cm/s; inexperienced: 1.24cm/s; 95%CI -0.45 to 0.24 cm/s, p=0.53).

Neither level of experience nor viewing order were related to polyp identification or gaze tracking metrics, therefore results are shown for all readers combined. For three metrics (proportion of gaze within central region, at least one polyp pursuit, time to first pursuit of polyp) multilevel model fitting was unreliable due to large variation between cases, so the results for these variables are presented descriptively.

True-positive polyp identification

The proportion of viewings during which the reader made a true-positive polyp identification decreased significantly at higher speed, from 56/77 (73%) of viewings at Speed 1 to 137/225 (61%) of viewings at Speed 4 (p=0.004, Tables 1 & 2). This effect of speed on true-positive polyp identification was highly case-dependent (Figure 1, crosses), which influences the estimate of the effect size. Some polyps (e.g. P7) showed a gradual decline in detection as speed increased, while others (e.g. P2, P5) had a consistent rate of polyp identification regardless of speed. Figure 2 shows the delaying effect of video speed on decision time for polyp identification, with clicks made while the polyp was visible (or within the allowed 500ms reaction time) tending to occur slightly later at faster speeds, relative to the total duration of the video.

False-positive polyp identification

The proportion of viewings with false-positive identifications also declined significantly with speed, from 42/115 (37%) at Speed 1 to 89/345 (26%) at Speed 4 (p=0.02, Tables 1 & 2). Figure 2 depicts clusters of false-positive identifications, implying the presence of specific endoluminal features provoking false-positives at all speeds, for example one-third of the way through video P8. These corresponded to diverticula, areas of faecal residue, or motion artefacts. The rate of false-positive identifications (taking into account video duration) was higher at faster speeds (Tables 1 & 2). In the sensitivity analysis (in which late clicks were treated as false-positive polyp identifications), the effect of speed was still evident (Tables 1 and 2).

Reader gaze distribution

Aggregated across all viewings, the proportion of time spent viewing the central 256x256 pixels increased from 84% at Speed 1 to 95% at Speed 4 (Table 1), illustrated by the heat-map in Figure 3. For 90 viewings (10% of total), readers' gaze did not move to the peripheral region of the screen throughout the entire video: 68 of these viewings were at Speed 4 and 22 were at Speed 3. There were no instances of such "tunnel-vision" at the two slowest speeds. An example of the influence of speed on the pattern of eye gaze for a single reader is shown as Supplemental Material Video and Figure 1. Reader gaze at Speed 1 shows comprehensive interrogation of the central field, with occasional visits to the periphery, whereas at Speed 4 the reader's gaze position becomes almost exclusively central.

Polyp eye gaze pursuits

At Speeds 1 and 2, a polyp pursuit was recorded in 90% and 97% of video viewings respectively. Only a single polyp was pursued on fewer than 90% of occasions at these slower speeds (P3; Figure 1, circles). This specific polyp was subjectively very inconspicuous (Supplemental Material Figure 2). Conversely, at higher navigation speeds, polyps were frequently not pursued; at Speed 4, the number of viewings with at least one polyp pursuit was only 119/223 (53%). Polyp pursuits decreased in line with increased viewing speeds, falling from an average of 3.2 per viewing at Speed 1 to 0.9 at Speed 4 ($p<0.001$; Table 1). Trends in time to first pursuit with respect to speed were highly case-dependent (Figure 4).

Despite several polyps exhibiting a particularly pronounced reduction in eye pursuits with increasing viewing speed (e.g. P1, P4, P5; Figure 1), this was not necessarily associated with a corresponding

reduction in polyp identifications. For example, for case P4 the polyp was identified by almost all readers at all speeds, even though fewer than 20% readers pursued this polyp at Speed 4. Identification was presumed due to peripheral vision.

Among viewings for which at least one polyp pursuit was achieved, the average proportion of time spent looking directly at the polyp did not vary across speeds (mean between 41% and 45% at each speed; Table 1).

Discussion

Endoluminal CTC is generally displayed from the perspective of a virtual colonoscope, and most workstations allow the reader to "fly-through" the lumen at their preferred speed (which we found was approximately 1.2cm/s). In this study, we found that as navigation speed increased, readers' gaze narrowed progressively to the central portion of the display; "tunnel vision". At the fastest speed, readers spent less than 5% of their time looking directly at the peripheral 75% of the image, thereby becoming almost entirely reliant on low-acuity peripheral vision here. A major advantage of CTC over colonoscopy is the former's ability to readily visualise the entire colonic mucosal surface[16]; our data suggest this can be negated by excessively hasty image navigation – the surface is displayed, but not interrogated by the reader. Accordingly, the percentage of true-positive polyp identifications reduced by over 10% at higher speeds, offset by a similar reduction in false-positive identifications. The effect of speed on polyp detection was highly dependent on the specific characteristics of the polyp being viewed.

Previous research investigating the effect of enforcing rapid radiological image interpretation is relatively scant. One study asked radiologists to interpret static 2D radiographs performed following extremity trauma[6]. When reporting at twice their normal rate, observer sensitivity was unchanged but the false positive rate dropped from 7.4% to 1.4%. A second study, using chest radiographs with lung nodules, varied interpretation time between 0.25 seconds and unrestricted. There was no significant difference in sensitivity or specificity vs. unlimited time once interpretation of at least 4 seconds was permitted; sensitivity only dropped once viewing times fell to 1 second or less[7]. More recently, the effect of rapid image interpretation on error rate for abdominopelvic CT has been investigated[17]. Radiologists were asked to interpret a sample of 12 CT studies at their normal rate and a further 12 cases at double this; the false-negative rate for major pathology was 10.0% at normal speeds versus 26.6% at the faster speed. Specificity was not reported. Taken together, these studies suggest that faster interpretation leads radiologists to overlook both true- and false-positive lesions, meaning that both sensitivity and the false-positive rate drop at higher interpretation speeds.

For endoluminal CTC specifically, we were able to demonstrate the likely underlying cause of this change in diagnostic test characteristics – the progressive narrowing of reader gaze with increased viewing speeds. The effect was particularly marked for speeds above 1.5cm/s, and a CTC workstation feature displaying navigation speed might therefore be a useful addition in clinical practice. However, at very slow speeds (e.g. 1.0cm/s), we found false positive identifications were relatively high, at 37%. These data present a dilemma for clinical practice; slow colonic navigation will likely maximise sensitivity, but at the cost of increased false-positives. Notwithstanding this, in most clinical scenarios (including CTC diagnosis of colorectal polyps specifically) diagnostic sensitivity is prioritised by both patients and doctors[18], implying slower navigation speeds would be preferable. It is notable that one performance indicator for colonoscopists is the "negative withdrawal time"[19]; the length of time an endoscopist spends inspecting the colon for examinations in which they did not find a polyp or cancer. This recognises the positive correlation between long withdrawal times and high adenoma detection rates. There is a clear analogy to be drawn with CTC interpretation, and therefore further work may be warranted to determine if either overall interpretation time or endoluminal navigation speed are associated with polyp detection at CTC.

This study has limitations. The endoluminal CTC videos we used do not reflect real-world CTC interpretation directly, and therefore we cannot be certain that the effects we observed are present in clinical practice. We portrayed videos at pre-specified fixed navigation speeds, whereas in reality readers will vary their speed as needed (for example, slowing down to navigate flexures). Also, we were only able to investigate a relatively limited number of different polyps and speeds, because piloting showed that a larger number provoked reader fatigue. Our power calculation and study results indicated that the sample size was sufficient to demonstrated differences in outcomes between speed settings, but our findings would have been stronger still if it had been possible to use a larger number of different videos and speeds. Although we selected these video speeds to encompass a plausible range of speeds that might be used clinically, no reader selected a preferred navigation speed beyond our faster velocities; therefore, the higher speeds we used (Speeds 3 and 4) were very unlikely scenarios in clinical practice. We asked readers to click a mouse to identify a polyp, whereas in reality a potential polyp causes readers to stop and perform detailed inspection, including correlation with 2D images, before a diagnostic decision is made. Although we have described such incorrect identifications as false-positives, this does not reflect the true false-positive rate for CTC because many would be dismissed following subsequent 2D inspection. Nonetheless, productivity and throughput would reduce due to the additional time required to interrogate the

increased number of polyp candidates, and ultimately might translate to a higher referral rate for (unnecessary) colonoscopy. Similarly, the fact that our simulated reading mode is not identical to that used in clinical practice may have also affected true-positive polyp identifications.

In conclusion**, as navigation speed increases, readers' gaze becomes more central and polyp identification rates fall.** Radiologists should consider reducing their navigation speed during interpretation of CTC in order to maximise sensitivity. Navigation speeds of over 1.5cm/s should be discouraged; this information could be displayed by CTC workstations.

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References

1. Laghi A. CT Colonography: an update on current and future indications. *Expert review of gastroenterology & hepatology* 2016: 1-10.
2. de Haan MC, Pickhardt PJ, Stoker J. CT colonography: accuracy, acceptance, safety and position in organised population screening. *Gut* 2015; **64**(2): 342-50.
3. Mang T, Kolligs FT, Schaefer C, Reiser MF, Graser A. Comparison of diagnostic accuracy and interpretation times for a standard and an advanced 3D visualisation technique in CT colonography. *Eur Radiol* 2011; **21**(3): 653-62.
4. Neri E, Vannozzi F, Vagli P, Bardine A, Bartolozzi C. Time efficiency of CT colonography: 2D vs 3D visualization. *Comput Med Imaging Graph* 2006; **30**(3): 175-80.
5. Kundel HL, Nodine CF. Interpreting chest radiographs without visual search. *Radiology* 1975; **116**(3): 527-32.
6. Edwards AJ, Ricketts C, Dubbins PA, Roobottom CA, Wells IP. The effect of reporting speed on plain film reporting errors. *Clin Radiol* 2003; **58**(12): 971-9.
7. Oestmann JW, Greene R, Kushner DC, Bourgouin PM, Linetsky L, Llewellyn HJ. Lung lesions: correlation between viewing time and detection. *Radiology* 1988; **166**(2): 451-3.
8. Phillips P, Boone D, Mallett S, et al. Method for tracking eye gaze during interpretation of endoluminal 3D CT colonography: technical description and proposed metrics for analysis. *Radiology* 2013; **267**(3): 924-31.
9. Halligan S, Altman DG, Mallett S, et al. Computed tomographic colonography: assessment of radiologist performance with and without computer-aided detection. *Gastroenterology* 2006; **131**(6): 1690-9.
10. Halligan S, Mallett S, Altman DG, et al. Incremental benefit of computer-aided detection when used as a second and concurrent reader of CT colonographic data: multiobserver study. *Radiology* 2011; **258**(2): 469-76.
11. R Core Team. R: A language and enviroment for statistical computing. R Foundation for Statistical Computing, Vienna.
12. Helbren E, Fanshawe TR, Phillips P, et al. The effect of computer-aided detection markers on visual search and reader performance during concurrent reading of CT colonography. *Eur Radiol* 2015; **25**(6): 1570-8.
13. Mallett S, Phillips P, Fanshawe TR, et al. Tracking eye gaze during interpretation of endoluminal three-dimensional CT colonography: visual perception of experienced and inexperienced readers. *Radiology* 2014; **273**(3): 783-92.
14. Helbren E, Halligan S, Phillips P, et al. Towards a framework for analysis of eye-tracking studies in the three dimensional environment: a study of visual search by experienced readers of endoluminal CT colonography. *Br J Radiol* 2014; **87**(1037): 20130614.
15. White IR, Royston P, Wood AM. Multiple imputation using chained equations: Issues and guidance for practice. *Stat Med* 2011; **30**(4): 377-99.
16. East JE, Saunders BP, Burling D, Boone D, Halligan S, Taylor SA. Surface visualization at CT colonography simulated colonoscopy: effect of varying field of view and retrograde view. *Am J Gastroenterol* 2007; **102**(11): 2529-35.
17. Sokolovskaya E, Shinde T, Ruchman RB, et al. The Effect of Faster Reporting Speed for Imaging Studies on the Number of Misses and Interpretation Errors: A Pilot Study. *J Am Coll Radiol* 2015; **12**(7): 683-8.
18. Boone D, Mallett S, Zhu S, et al. Patients' & healthcare professionals' values regarding true- & false-positive diagnosis when colorectal cancer screening by CT colonography: discrete choice experiment. *PLoS One* 2013; **8**(12): e80767.
19. Lee TJW, Rutter MD, Blanks RG, et al. Colonoscopy quality measures: experience from the NHS Bowel Cancer Screening Programme. *Gut* 2012; **61**(7): 1050-7.

TABLES

Table 1: Summary of metrics by speed, displayed as number (%), mean (standard deviation) or median [inter-quartile range]. Speed 1 = 1.0cm/s, Speed 2 = 1.5cm/s, Speed 3 = 3.0cm/s, Speed 4 = 4.5cm/s.

Metric	**Speed 1**	**Speed 2**	**Speed 3**	**Speed 4**
True-positive identification	56 / 77 (73%)	54 / 77 (70%)	153 / 231 (66%)	137 / 225 (61%)
False-positive identification				
Primary analysis	42 / 115 (37%)	33 / 115 (29%)	89 / 345 (26%)	89 / 345 (26%)
Sensitivity analysis	55 / 115 (47%)	45 / 115 (39%)	116 / 345 (34%)	110 / 345 (31%)
Proportion of gaze within central region (%)	86% [77%, 92%]	89% [83%, 93%]	95% [91%, 97%]	97% [95%, 100%]
Pursuits of polyp				
At least one	69 / 77 (90%)	75 / 77 (97%)	177 / 229 (77%)	119 / 223 (53%)
Number per viewing	3.2 (3.7)	2.4 (1.7)	1.5 (1.4)	0.9 (1.1)
Rate (s^{-1})	0.59 (0.38)	0.67 (0.33)	0.80 (0.57)	0.62 (0.70)
Time to first pursuit of polyp, among viewings with at least one pursuit (%)	15% [3%, 20%]	17% [3%, 34%]	20% [3%, 52%]	8% [0%, 37%]
After excluding immediate pursuits	16% [7%, 22%]	23% [8%, 35%]	34% [10%, 54%]	21% [8%, 52%]
False positive identifications				
Number per viewing	0.56 (0.91)	0.36 (0.61)	0.33 (0.63)	0.29 (0.53)
Rate (× 10 s^{-1})	0.17 (0.33)	0.18 (0.35)	0.38 (0.72)	0.45 (0.86)
Total pursuit time (%)	39% [21%, 63%]	39% [26%, 56%]	31% [10%, 48%]	14% [0%, 36%]
Among viewings with at least one pursuit	43% [29%, 64%]	39% [36%, 57%]	38% [25%, 53%]	32% [20%, 60%]

Table 2: Comparison of metrics between speeds, derived from multilevel models, and expressed relative to Speed 1 as odds ratio (OR) or rate ratio (RR) as appropriate, with 95%CI and p-value. Speed 1 = 1.0cm/s, Speed 2 = 1.5cm/s, Speed 3 = 3.0cm/s, Speed 4 = 4.5cm/s.

Metric	**Measure**	**Speed 2**	**Speed 3**	**Speed 4**
True positive identification	OR	0.48 (0.17, 1.32) p=0.16	0.46 (0.20, 1.08) p=0.07	0.29 (0.12, 0.68) p=0.004
False positive identification				
Primary analysis	OR	0.71 (0.36, 1.42) p=0.34	0.56 (0.32, 0.97) p=0.04	0.53 (0.30, 0.92) p=0.02
Sensitivity analysis	OR	0.64 (0.35, 118) p=0.15	0.48 (0.29,0.79) p=0.004	0.43 (0.26, 0.71) p=0.001
Pursuits of polyp				
Number per viewing	RR	0.71 (0.58, 0.87) p<0.001	0.44 (0.37, 0.52) p<0.001	0.25 (0.21, 0.30) p<0.001
Rate (s^{-1})	RR	1.07 (0.87, 1.30) p=0.53	1.32 (1.11, 1.56) p=0.002	1.16 (0.95, 1.41) p=0.13
False positive identifications				
Number per viewing	RR	0.70 (0.47, 1.05) p=0.08	0.65 (0.48, 0.88) p=0.006	0.56 (0.40, 0.76) p<0.001
Rate (× 10 s^{-1})	RR	1.04 (0.60, 1.81) p=0.88	2.33 (1.55, 3.51) p<0.001	2.58 (1.69, 3.95) p<0.001
Total pursuit time, among viewings with at least one pursuit (%)	OR	0.93 (0.68, 1.27) p=0.66	0.87 (0.67, 1.13) p=0.29	0.82 (0.62, 1.10) p=0.18

FIGURE LEGENDS:

Figure 1: Percentage of all viewings, at each speed, for which there was at least one pursuit, and for which there was at least one polyp identification. Separate figures are shown for each true positive case (P1-P8). Percentages in brackets are the proportion of the total video duration during which the polyp was on the screen. The total number of viewings is shown as N.

Figure 2: Timing of all polyp identifications for all video viewings. Each polyp identification is shown as a single point, separately for each speed. Times are shown as the proportion of the whole video duration; hence, the x-axis refers to a longer period in real time for videos at slower speeds. Periods when the polyp was on screen are indicated by the shaded rectangles, and the allowed reaction time is indicated by a vertical dash. Cases N1-N4: without polyps, P1-P8: with polyps.

Figure 3: Heat map showing recorded eye locations when no polyp was visible, aggregated over all viewings at each speed. The outer solid 512x512-pixel square indicates the monitor's display area, and the inner dashed 256x256-pixel square the central region.

Figure 4: Time to first pursuit of polyp, expressed as a percentage of the period the polyp was onscreen, at each speed. Each point represents one viewing, and the lines connect the median at each speed. Separate figures are shown for each true positive case (P1-P8). Immediate pursuits (time 0%) are excluded. For case P5, there were no pursuits of the polyp at Speed 4.

Supplementary Figure 1 and Video: Video depicting reader gaze for two viewings of the same case (Polyp P4) at Speed 1 and Speed 4. Gaze is shown as a semi-translucent blue marker on the video, and as a heat map in the figure, with warmer (redder) colors corresponding to longer gaze times.

Supplementary Figure 2: Polyp P3 (arrow), subjectively very subtle and infrequently pursued even at slow speeds