Title

Technical report: Inter- and intra-rater reliability of regional gastrointestinal transit times measured using the 3D-Transit electromagnet tracking system

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Abstract

Background: The 3D-Transit electromagnet tracking system is an emerging tool for the ambulatory assessment of gastrointestinal (GI) transit times and motility patterns, based on the anatomical localization of ingestible electromagnetic capsules. Currently, 3D-Transit recordings are manually analyzed to extract GI transit times. As this is a subjective method, there is some inherent variability in the measurements, which may be experience-dependent. We therefore assessed inter- and intra-rater reliability of GI transit times from 3D-Transit recordings.

Methods: Thirty-six 3D-Transit recordings (17 female; median age: 34 years (range: 21–80)) were analyzed twice by 3 raters with varying experience. Each rater manually identified the timestamps when a capsule progressed from antrum to duodenum, and from ileum to right colon. These timestamps, along with the ingestion and expulsion times were used to determine whole gut (WGTT), gastric emptying (GET), small intestinal (SITT) and colonic (CTT) transit times. Reliability was determined using interclass correlation coefficient (ICC).

Key Results: For capsule progression timestamps, the most and mid-experienced raters had fair to good inter- and excellent intra-rater reliability ($ICC_{min-max}$=0.61-1.00), whereas the inexperienced rater had poor to fair inter- and poor intra-rater reliability ($ICC_{min-max}$=0.28-0.55). GET and SITT reliability between the most and mid-experienced raters was fair ($ICC_{min-max}$=0.61-0.73), while reliability between these raters and the inexperienced rater was poor to fair ($ICC_{min-max}$=0.28-0.55). CTT reliability was excellent between and within all raters ($ICC_{min-max}$=0.92-0.99).

Conclusions & Inferences: Inexperienced raters provide the least reliable measurements from 3D-Transit recordings, which confirms requirement for adequate training. Automation may improve reliability of measurements.

Key Points

- The 3D-Transit System can aid the diagnostic evaluation of gastrointestinal disorders. We assessed the reliability of regional GI transit times measured by experienced and inexperienced raters.
- Reliability of gastric emptying and small intestinal transit time was fair between the most and mid-experienced raters but poor for the inexperienced rater. Whole gut and colonic transit time reliability was excellent across all raters.
- Inexperienced raters require adequate training to provide reliable measurements of GI transit times from the 3D-Transit System.

Key Words

3D-Transit system, electromagnetic capsule, gastrointestinal, reliability, transit time

Abbreviations

GI: gastrointestinal; cpm: contractions per minute; WGTT: whole gut transit time; GET: gastric emptying; SITT: small intestinal transit time; CTT: colonic transit time; ICC: intraclass correlation coefficient; CI: confidence interval.

Introduction

The 3D-Transit electromagnet tracking system (Motilis Medica, SA, Lausanne, Switzerland) is a novel and minimally invasive tool for the ambulatory evaluation of total and regional gastrointestinal (GI) transit times and motility patterns. It accurately tracks and measures the position and orientation of up to three ingestible electromagnetic capsules from ingestion to expulsion using an external detector plate positioned over the abdomen.[1-4]

Total GI transit time is easily extracted from a 3D-Transit recording, as the signal start and end points indicate capsule ingestion and expulsion times. For regional GI transit times however, the timestamps when a capsule progresses from the stomach into the duodenum, and from the ileum into the right colon are manually identified by visually observing changes in the capsule's orientation angles, which reflect GI contractile activity, along with shifts in its position as it progresses from one GI region to the next.[1,5]

The system was originally developed using a stationary detector matrix which required subjects to stay relatively immobile for long periods of time in a controlled laboratory environment, thus reducing the effects of external movement artefacts.[6-9] Accordingly, inter-rater variability in capsule progression timestamps, and thereby GI transit times, has been reported as low.[6,8] The principle advantage of the ambulatory system is that it enables continuous monitoring of GI motility under physiological conditions; however, subject ambulation renders it susceptible to external magnetic fields and motion artifacts, making it more difficult to identify capsule progression timestamps. Hence, the accuracy in identifying these timestamps is not only dependent on the quality of the recording but also on the ability of the rater to distinguish artifacts from real movements of the capsule.

Recently, the inter-variability of GI transit time measurements was assessed by two experienced raters who analyzed 20 3D-Transit recordings.[1] Differences in regional GI transit times were reported in 8 of the 20 recordings (40%); however, these differences were considered acceptable by the authors, as the overall median difference was zero minutes.[1] Nevertheless, there is a need to determine the level of reliability of measurements, particularly when raters are blinded to their own and each other's results. Therefore, the primary aim of this study was to assess inter- and intra-rater reliability of capsule progression timestamps, and hence regional GI transit times. A secondary aim was to assess how the experience of the rater influences the identification of these timestamps.

Materials & Methods

3D-Transit recording selection

3D-Transit recordings were selected from a database of healthy volunteer studies conducted at the Neurogastroenterology Unit at Aarhus University Hospital (Aarhus, Denmark), Department of Gastroenterology and Hepatology at Aalborg University Hospital (Aalborg, Denmark) and the GI Physiology Unit at Queen Mary University (London, UK) between March 2012 and February 2016. In these studies, healthy volunteers swallowed up to three capsules, each taken a day apart after an overnight fast. Recordings were selected if they were complete with clear ingestion and expulsion points. For studies where volunteers ingested more than one capsule, only one recording was selected irrespective of capsule number. Poor quality recordings or recordings with more than 2 hours of missing data were excluded from the study. From this, a sample of 36 3D-Transit recordings were randomly selected (17 female; median age: 34 years (range: 21–80)), 12 from each research center.

Data Collection

Three independent raters with varying experience of analyzing 3D-Transit recordings participated in the study. Rater experience was based on the number of previously analyzed recordings as follows: ≥100 recordings: most experienced (rater 1); approximately 40 recordings: mid-experienced (rater 2); <5 recordings: least experienced (rater 3). All raters were prescribed written instructions on analyzing 3D-Transit recordings (dated May 2017) and the 3D-Transit System Instructions for Use (dated September 2014).

Recordings were analyzed using the 3D-Transit software, version 0.4 (Motilis Medica, SA, Lausanne, Switzerland). This involved identifying four timestamps as described by Haase et al. (2014)[1]: **(i) ingestion**: start of recording; **(ii) duodenum**: capsule's progression from the stomach into the duodenum; **(iii) right colon:** capsule's progression from the distal ileum to the caecum; **(iv) expulsion:** end of recording indicated by a loss of signal. For intra-rater reliability, each rater analyzed the 36 recordings twice with a minimum period of two weeks between repeat analyses.

Data Analysis

The timestamps were used to determine WGTT (whole gut transit time; time between capsule ingestion and expulsion), GET (gastric emptying; time between ingestion and passage into the duodenum), SITT (small intestinal transit time; time between the duodenum and right colon timestamps) and CTT (colonic transit time; time between the right colon timestamp and capsule expulsion). Transit times were automatically extracted from the 3D-Transit software and exported as text files for inter- and intra-rater comparison.

Statistical Analysis

To calculate inter- and intra-rater reliability of the duodenum and right colon timestamps and regional transit times, the ICCs (intraclass correlation coefficients) and their 95% confidence intervals (CIs) were calculated based on a single rating, absolute agreement, 2-way random-effects model. ICC values range between 0 and 1 with a higher value indicating better reliability (<0.5, poor; 0.5-0.75, fair; 0.75-0.9, good; >0.9, excellent).[10] The timestamps were subtracted from the ingestion timestamp to convert the data into hours for the ICCs to be determined. Scatterplots, means and 95% CI were used to illustrate and compare GI transit times within and between raters. All statistical analyses were performed using SPSS Statistics Version 25 (IBM, New York, USA).

Results

Inter-rater reliability of duodenum and right colon timestamps

Between raters, the degree of inter-rater reliability of both the duodenum and right colon timestamps was poor, with the ICC ranging between 0.42 and 0.47 (95% CI = 0.24-0.63). However, when comparing the most and mid-experienced raters, the reliability of both timestamps was fair to good. Reliability between raters 1 (most-experienced) and 2 (mid-experienced) against rater 3 (least-experienced) was poor to fair for the duodenum timestamp and very poor for the right colon timestamp (Table 1).

Intra-rater reliability of duodenum and right colon timestamps

Intra-rater reliability of both timestamps was good to excellent for raters 1 and 2 with the ICC ranging between 0.89 and 1.00 (95% CI = 0.79-1.00). However, reliability of these timestamps was poor for rater 3 (Table 1).

Inter-rater reliability of regional GI transit times

Scatterplots for inter-rater reliability of whole gut and regional GI transit times are presented in Figure 1. GET and SITT reliability between all raters was low, supported by poor ICCs ranging between 0.41 and 0.47 (95% CI = 0.25-0.63), while reliability of CTT was excellent (Table 2). ICC values for GET and SITT were consistently fair between raters 1 and 2, while reliability between these raters and rater 3 was poor. WGTT reliability was excellent across all raters.

Intra-rater reliability of regional GI transit times

Scatterplots for intra-rater reliability are presented in Figure 2. For raters 1 and 2, good to excellent intra-rater reliability was seen for GET and SITT, with ICC values ranging between 0.84 and 1.00 (95% CI = 0.71-1.00), while reliability was poor for rater 3 (ICC = 0.20-0.48, 95% CI = -0.14-0.71) (Table 2). CTT and WGTT reliability was excellent for all raters.

Discussion

We assessed the inter- and intra-rater reliability of regional GI transit times based on the manual identification of the duodenum and right colon capsule progression timestamps in 3D-Transit recordings. Our results showed that the inter- and intra-rater reliability of both timestamps is generally fair to excellent amongst the most and mid-experienced raters and as expected, poor in an inexperienced rater. This explains the fair inter-rater, and good to excellent intra-rater reliability of GET and SITT seen amongst the more and mid experienced raters. However, reliability of these transit times was poor in the inexperienced rater, indicating a need for an adequate period of training.

Surprisingly, the inter- and intra-rater reliability of CTT was excellent amongst all raters. This was unexpected, as the CTT is dependent on the right colon timestamp, the reliability of which was poor in the inexperienced rater. Furthermore, general consensus amongst all raters was that the right colon timestamp was subjectively more difficult to identify than the duodenum. However, this may be explained by examining the magnitudes of the measurements. CTT is approximately eight times longer than GET, and four times longer than SITT; therefore, the CTT measurement is less sensitive to the uncertainty in the right colon timestamp due to its large magnitude and a fixed capsule expulsion timestamp.

Nevertheless, it is apparent that the manual method of analyzing 3D-Transit recordings is not optimal, even amongst experienced raters who only showed fair inter-rater reliability for GET and SITT. Furthermore, the reliability of GI transit times was assessed using good quality recordings.

Poorer quality recordings, which are difficult to interpret due to the increased presence of artifacts may produce less reliable measurements. Therefore, there is a need to improve the current methodology to obtain better estimates of GI transit times. This may be achieved through automation by using artifact rejection algorithms and pattern-recognition techniques to better detect the various gut contraction frequencies and hence, the capsule progression timestamps.

In conclusion, we assessed the inter- and intra-rater reliability of GI transit times as measured using the 3D-Transit system. Reliability was generally fair between experienced raters. An inexperienced rater provided the least reliable results, indicating a need for adequate training. Automation may improve reliability of the method.

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Disclosure

The authors have no competing interests.

Author Contribution

GKK and MJB designed the study. GKK, DG and JM collected the data. GKK and DG analyzed the data and drafted the initial manuscript. GKK completed and finalized the manuscript. AMD, SMS and MJB reviewed and approved the final manuscript as submitted. All authors have approved this version of the manuscript.

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Figure Legends

Figure 1: Inter-rater reliability of total and regional GI transit times compared across raters where rater 1 is most experienced, rater 2 is mid-experienced and rater 3 is least experienced. GET, gastric emptying; SITT, small intestine transit time; CTT, colonic transit time; WGTT, whole gut transit time. All transit times are in hours.

Figure 2: Comparison of first and repeat analyses to assess intra-rater reliability of total and regional GI transit times within raters, where rater 1 is most experienced, rater 2 is mid-experienced and rater 3 is least experienced. GET, gastric emptying; SITT, small intestine transit time; CTT, colonic transit time; WGTT, whole gut transit time. All transit times are in hours.

Table Captions

Table 1: Inter- and intra-rater reliability of duodenum and right colon timestamps between and within raters of varying levels of experience where rater 1 (R1) is most experienced, rater 2 (R2) is mid-experienced and rater 3 (R3) is least experienced.

Table 2: Inter- and intra-rater reliability of regional GI transit times between and within raters of varying levels of experience where rater 1 (R1) is most experienced, rater 2 (R2) is mid-experienced and rater 3 (R3) is least experienced. GET, gastric emptying; SITT, small intestine transit time; CTT, colonic transit time; WGTT, whole gut transit time.

Table 1

TEST	ICC (95% CI)
INTER-OBSERVER ANALYSIS	
Duodenum Timestamp	
R1-R2-R3¨	0.47 (0.32 – 0.63)
R1-R2†	0.61 (0.45 – 0.75)
R1-R3†	0.55 (0.38 – 0.71)
R2-R3†	0.47 (0.27 – 0.65)
Right Colon Timestamp	
R1-R2-R3¨	0.42 (0.24 – 0.60)
R1-R2†	0.82 (0.72 – 0.89)
R1-R3†	0.28 (0.10 – 0.48)
R2-R3†	0.30 (0.11 – 0.50)
INTRA-OBSERVER ANALYSIS	
Duodenum Timestamp	
R1[§]	0.96 (0.92 – 0.98)
R2[§]	1.00 (0.99 – 1.00)
R3[§]	0.48 (0.16 – 0.71)
Right Colon Timestamp	
R1[§]	0.89 (0.79 – 0.94)
R2[§]	0.93 (0.87 – 0.96)
R3[§]	0.28 (-0.34 – 0.55)

¨Pooled values from 6 measurements (first and repeat analyses)
† Pooled values from 4 measurements (first and repeat analyses)
§Pooled values from 2 measurements (first and repeat analyses)

Table 2

TEST	MEAN (95% CI)*	ICC (95% CI)
INTER-RATER ANALYSIS		
Gastric Emptying Time (GET)		
R1-R2-R3¨	3.2 (2.8-3.6)	0.47 (0.32-0.63)
R1-R2†	3.7 (3.1-4.2)	0.61 (0.45-0.75)
R1-R3†	2.6 (2.3-2.9)	0.55 (0.38-0.71)
R2-R3†	3.3 (2.8-3.8)	0.47 (0.27-0.65)
Small intestine transit time (SITT)		
R1-R2-R3¨	6.3 (5.8-6.8)	0.41 (0.25-0.58)
R1-R2†	7.3 (6.7-8.0)	0.73 (0.61-0.84)
R1-R3†	6.1 (5.5-6.7)	0.28 (0.11-0.48)
R2-R3†	5.6 (5.1-6.1)	0.32 (0.15-0.51)
Colonic transit time (CTT)		
R1-R2-R3¨	24.3 (22.4-26.2)	0.94 (0.88-0.97)
R1-R2†	22.8 (20.5-25.2)	0.98 (0.97-0.99)
R1-R3†	25.2 (22.8-27.5)	0.93 (0.84-0.97)
R2-R3†	25.0 (22.6-27.3)	0.92 (0.82-0.96)
INTRA-RATER ANALYSIS		
Gastric Emptying Time (GET)		
R1§	3.0 (2.5-3.4)	0.96 (0.92-0.98)
R2§	4.4 (3.4-5.4)	1.00 (0.99-1.00)
R3§	2.2 (1.9-2.5)	0.48 (0.16-0.71)
Small intestine transit time (SITT)		
R1§	7.9 (6.9-8.9)	0.86 (0.75-0.93)
R2§	6.8 (6.0-7.6)	0.84 (0.71-0.92)
R3§	4.4 (3.8-4.9)	0.20 (-0.14-0.50)
Colonic transit time (CTT)		
R1§	23.0 (19.7-26.3)	0.99 (0.98-0.99)
R2§	22.7 (19.3-26.0)	0.99 (0.98-1.00)
R3§	27.3 (24.0-30.6)	0.97 (0.94-0.99)

* Values expressed in hours
¨Pooled values from 6 measurements (first and repeat analyses)
† Pooled values from 4 measurements (first and repeat analyses)
§Pooled values from 2 measurements (first and repeat analyses)

Figure 1

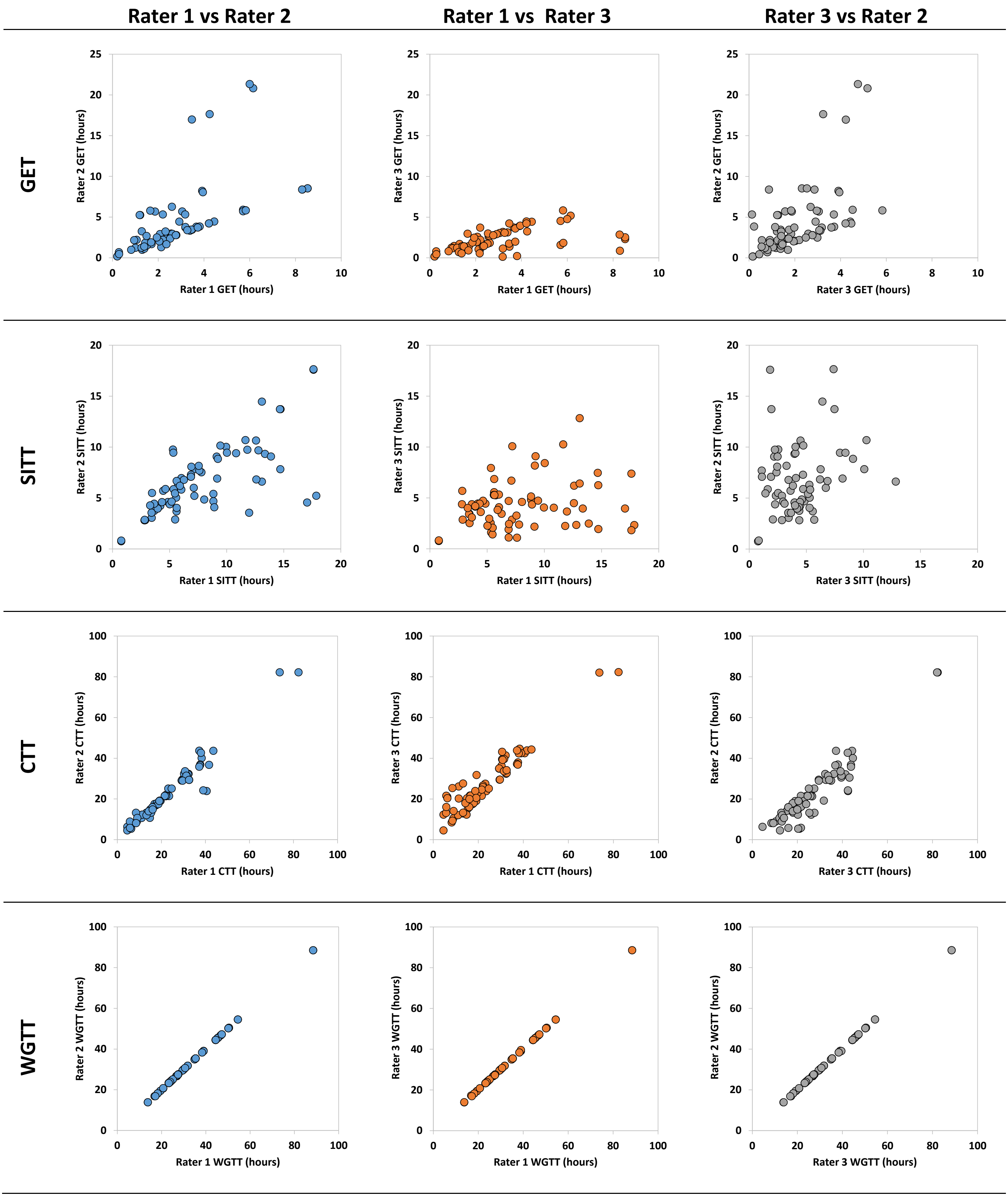
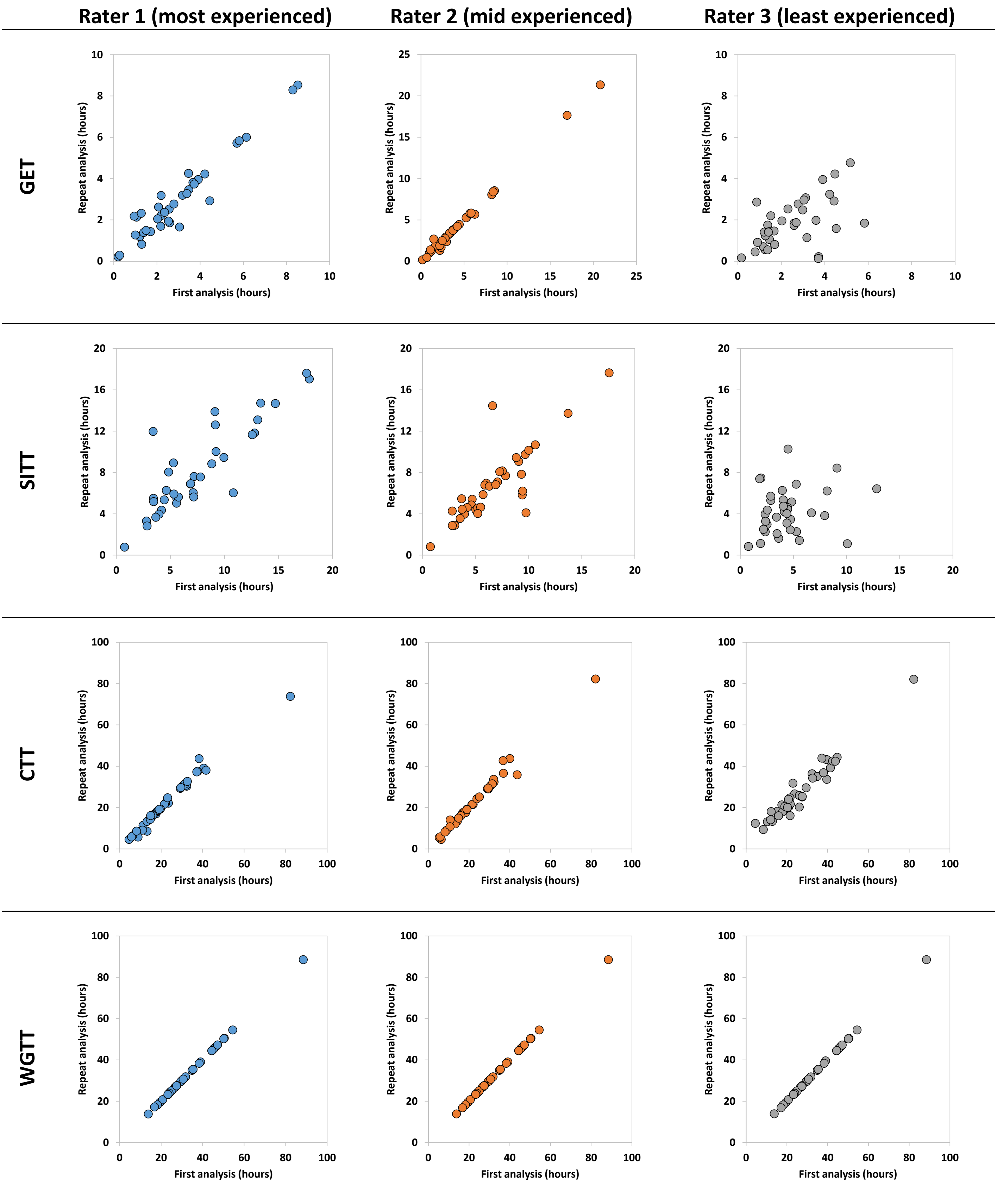

Rater 1 vs Rater 2
Rater 1 vs Rater 3
Rater 3 vs Rater 2
GET
SITT
CTT
WGTT
Rater 2 GET (hours)
Rater 3 GET (hours)
Rater 1 GET (hours)
Rater 3 GET (hours)
Rater 2 SITT (hours)
Rater 3 SITT (hours)
Rater 1 SITT (hours)
Rater 3 SITT (hours)
Rater 2 CTT (hours)
Rater 3 CTT (hours)
Rater 1 CTT (hours)
Rater 3 CTT (hours)
Rater 2 WGTT (hours)
Rater 3 WGTT (hours)
Rater 1 WGTT (hours)
Rater 3 WGTT (hours)

Figure 2



Rater 1 (most experienced)
Rater 2 (mid experienced)
Rater 3 (least experienced)
GET
SITT
CTT
WGTT
Repeat analysis (hours)
First analysis (hours)

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