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Feasibility of a digital clock test

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A novel digital clock drawing test as a screening tool for perioperative neurocognitive disorders: A feasibility study

Short title: Feasibility of a digital clock test

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Abstract

Background

We developed a digital clock drawing test (dCDT), an adaptation of the original pen and paper clock test, that may be advantageous over previous dCDTs in the perioperative environment. We trialled our dCDT on a tablet device in the preoperative period to determine the feasibility of administration in this setting. To assess the clinical utility of this test, we examined the relationship between the performance on the test and compared derived digital clock measures with the 4 A's Test (4AT), a delirium and cognition screening tool.

Methods

We recruited a sample of 102 adults aged 65 years and over presenting for elective surgery in a single tertiary hospital. Participants completed the 4AT, followed by both command and copy clock conditions of the dCDT. We recorded time-based clock-drawing metrics, alongside clock replications scored using the Montreal Cognitive Assessment (MoCA) clock scoring criteria.

Results

The dCDT had an acceptance rate of 99%. After controlling for demographic variables and prior tablet use, regression analyses showed higher 4AT scores were associated with greater dCDT time (seconds) for both command ($\beta=8.2$, $p=0.020$) and copy clocks ($\beta=12$, $p=0.005$) and lower MoCA-based clock scores in both command (OR=0.19, $p=0.001$) and copy conditions (OR=0.14, $p=0.012$).

Conclusion

The digital clock drawing test is feasible to administer and is highly acceptable to older adults in a preoperative setting. We demonstrated a significant association between both the dCDT time and clock score metrics, with the established 4AT. Our results provide convergent validity of the dCDT in the preoperative setting.

Editorial Comment: Elderly patients with pre-existing cognitive disorders have an increased risk of postoperative cognitive dysfunction. This study investigated the feasibility of a novel, tablet-based digital clock drawing test that was developed specifically for preoperative use and administered to patients aged 65 years or above. Patient acceptance rate was high, and this step was easily managed in the preoperative workflow. Performance on the new test was associated with performance on the 4 A's Test, indicating convergent validity.

Introduction

As the population ages, patients with undiagnosed cognitive impairment are increasingly presenting for surgical procedures.^{1,2} Cognitive impairment is a known risk factor for perioperative neurocognitive disorders (PND) such as postoperative delirium (POD) and delayed neurocognitive recovery (dNCR).³⁻⁵ Studies report that 20 - 30% of patients aged 65 years or more presenting for surgery have some form of pre-existing cognitive impairment.^{6,7} Preoperative neurocognitive screening may mitigate the risk of postoperative complications, such as POD by facilitating perioperative planning and informed decision making between patients, families and medical staff.^{4,8-10} With the prominence of 'same-day' surgical admissions, the immediate perioperative period may be the only opportune time to assess the cognitive function of these patients, highlighting the need for brief and effective screening tools.

Ideal perioperative cognitive screening tools are fast, reliable, easy to administer and can be used across groups of varying cultures, education and language proficiency levels. Despite the range of tools currently available, there is a lack of consensus on the most appropriate tool for screening cognitive impairment in the perioperative environment. Current cognitive assessment tools, such as the Mini-cog¹¹ and the 4A's Test (4AT)¹² have been deemed feasible for the perioperative use,^{13,14} however many tools are limited by staff training requirements, acceptance by staff, sensitivity, variability in scoring, language barriers and time constraints.¹⁴⁻¹⁷

A potential alternative to pen and paper-based screening tools is the digital clock drawing test (dCDT). Similar to the traditional test, the most common dCDT conditions are the 'command' and 'copy' clock tests. The command clock requires respondents to freely recall and draw the face of a clock; in the copy condition, respondents replicate the image of a clock presented to them. Multiple cognitive domains are involved in the successful completion of both versions of the dCDT, including visuospatial construction, executive function and attention,¹⁸⁻²¹ making it a sensitive screening tool for cognitive impairment.

Although previous studies demonstrate that the traditional pen and paper clock drawing test is suitable for the perioperative period,^{10,14} there is variability in the dCDT's patient acceptability, and incompatibility with some Electronic Medical Record systems. These limitations may be overcome with a new digitised version.¹⁷ dCDT tools allow researchers to objectively obtain additional drawing metrics, such as the time taken to draw individual elements of the clock, a feature which may make the dCDT advantageous over the standard paper-based test.²² Current iterations of the dCDT utilise digitised pens which are single purpose, bulky to draw with and require ink and paper.²³ Furthermore, current dCDT devices are limited by an inability to remotely connect to computers, instead requiring a physical connection to transfer data.

A tablet based dCDT may address the limitations of previous pen-based dCDT iterations and other tablet-based tools, but to-date has not been examined with older adults in the immediate perioperative period. Establishing the acceptability of clock drawing on tablet devices in this population is critical as older people may be less familiar with electronic devices, resulting in poor performances attributable to test suitability, rather than cognitive impairment *per se*. Current literature exploring the impact of tablet device proficiency on computerised cognitive testing performance is mixed.²⁴⁻²⁶ In terms of other interactive tablet software, the authors are aware of several computerised cognitive assessment tools,²⁷⁻²⁹ which may be used in the preoperative period. However, in this setting, acceptability, efficiency of administration in addition to sensitivity are of prime importance.

The aim of the present study was to 1) develop a novel tablet-based dCDT tool for the perioperative environment addressing some of the limitations of previous pen-based dCDT tools, and 2) assess patient acceptability and the feasibility of administering the dCDT to older adults in the perioperative environment. As secondary aims we also examined the impact of prior tablet use on dCDT performance and established the concurrent validity of the new tool by examining the relationship between our tablet-based dCDT and the 4AT.

Materials and Methods

Participants

Participants were recruited from the day surgery pre-operative admission centre at St Vincent's Hospital, Melbourne, Australia over a two-week period in November 2019. We used a convenience sampling approach and screened patients for eligibility from the daily operating room lists on the day prior to surgery. The study received ethical approval from St. Vincent's Hospital Human Research Committee (SVH-HREC 181/19) as a low-risk activity; all participants provided verbal informed consent.

Patients were invited to participate if they were 65 years or older, undergoing an elective surgical procedure and had capacity to provide verbal informed consent. Capacity to

provide informed consent was evidenced if the participant had consented for their own surgical procedure. We excluded people with physical or sensory deficits (e.g. vision, hearing, tremor) expected to prevent participation or people who had an overnight hospital stay prior to their procedure. Baseline characteristics including age, sex, and years of education were obtained for all participants. This study adheres to The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guidelines.³⁰

Tablet-Based dCDT

Before assessing the feasibility of a new dCDT on a tablet device, we first designed a dCDT application that was compatible with an Apple 9.7" iPad (® Apple Corporation, 6th generation), and a 1st generation Apple ® pencil. The dCDT application was conceived and designed by the author (R.B.) and produced in conjunction with an external software coder (see acknowledgements). The intellectual property for this program is held by R.B. The application to acquire the dCDT image and metrics was written in Swift 5 ® (Apple Corporation, California, USA) for an iOS 12 operating system. This dCDT system was designed to capture a range of drawing variables, including drawing latencies and number of strokes, as well as storing the completed drawing suitable for conventional scoring (e.g., MoCA clock drawing score). For the purposes of this study we used the total time spent drawing (including time between drawing strokes) referred to as "dCDT time" and a total score based on MoCA clock drawing criteria.^{22,23} We selected these variables as they most closely reflect the variables of interest in the traditional paper and pencil test. Our application allowed for easy transfer of clock data to electronic patient medical records or standard analytic software (e.g. spreadsheet or statistical programs). The software functions as a standalone application and thus although compatible with electronic medical records, can also function independently of hospital/clinic software. The software had a drawing space equivalent to 222.3 cm² (width 14.78 cm and height 15.04 cm).

To assess feasibility we evaluated the dCDT against the recommendations described by Bowen et al.³¹ We considered the extent that the dCDT met criteria for: 1) acceptability to patients, 2) demand for preoperative cognitive screening tools, 3) ease of implementation, 4) practicality, 5) flexible adaptation of the tool, 6) integration into existing hospital systems, 7) areas of expansion, and 8) efficacy. We systematically evaluated our tablet-based dCDT against these criteria to determine the feasibility and validity of our tool with older adults in the preoperative environment.

The 4AT

The 4AT is a relatively fast and easy-to-administer paper-based tool that screens for delirium and cognitive impairment and is recommended by the Australian Commission on

Safety and Quality in Health Care.^{12,15,32} The test comprises four sections that are delivered verbally: 1) assessment of alertness, 2) Abbreviated Mental Test – 4 (AMT4), 3) attention assessment via months backward test and, 4) assessment of acute cognitive change. Item scores are summated for a total scale score ranging from 0-12, with zero indicating ‘unlikely’ cognitive impairment and greater than zero indicating, “possible cognitive impairment”.¹⁵

Procedure

Eligible patients were invited to participate and were assessed by one investigator (R.B.) in the day procedures waiting room prior to their procedure. Given the single assessor and availability of a single device, not all patients who may have been eligible to participate were able to be approached. Upon providing verbal consent, participants provided information including their age, level of education, handedness, prior touch screen use (greater than once per week versus none). We then administered the 4AT.

Next, participants were familiarised with the tablet device by instructing them to draw a square on the screen. This phase was not scored in the study. This ensured a baseline level of competence with the device before proceeding with the testing. The command clock was administered first with participants given 3 commands: “Please draw a clock face; put in all of the numbers; set the hands to ten past eleven”.³³ Instructions were repeated if requested by the participant. Following the command clock, participants were asked to complete the copy clock. An image of a correctly drawn clock on a laminated piece of paper was provided, alongside the verbal instructions, “Please copy this image”. Participants were provided as much time as necessary to complete each assessment.

The dCDT clock drawings were scored by two members of the research team according to MoCA clock scoring criteria (0 = worst, 3 = best).³³ The MoCA clock scoring criteria were chosen over more detailed criteria,^{34,35} because of their ease of application and consistency of administration.²¹ Any discrepancies in scoring were discussed and resolved by consensus with a neuropsychology registrar who is a member of the research team (K.A.).

Statistical analysis

Using Spearman’s rank correlation coefficients, we examined the relationship between participant characteristic variables and the dCDT command and copy clock variables. We used linear regression to evaluate how 4AT scores and prior tablet use affected dCDT time. To examine the impact of 4AT and prior tablet use on dCDT scores, we used logistic regression. For the purpose of these regressions we used a MoCA clock score of >1 to indicate normal cognition for both command and copy conditions.²¹ A Wilcoxon Rank Sum Test was performed to assess differences between participants with 4AT = 0 and

4AT > 0 on dCDT time and clock score across both command and copy clocks. This grouping was based on the official cut off scores for the 4AT of which a score greater than zero indicates “possible cognitive impairment”.¹⁵ Finally, weighted Kappa statistics were conducted to assess inter-rater reliability. All data was analysed using STATA® 15.1 (STATA Corp LLC, Texas, USA). Although no power analyses were undertaken, we sought to recruit 20-30 participants with some degree of cognitive impairment which, based on our previous data, alongside others, would require 100 participants.^{6,7}

Results

A total of 103 patients were approached, of whom 102 agreed to participate and completed all study assessments, including familiarisation with the device, resulting in an acceptance rate of 99% (Figure 1). Participant characteristics for this sample are presented in Table 1. When assessed against feasibility recommendations provided by Bowen et al, the dCDT appeared highly feasible for the preoperative environment (Table 2). In our study the dCDT was flexibly implemented into the preoperative workflow demonstrated by its ease of use, patient acceptability and versatile administration.

Inter-rater reliability of MoCA clock scores was 0.72 (95% CI = [0.67, 0.74]) indicating substantial agreement between raters. A 4AT score greater than zero, suggestive of cognitive impairment,³⁶ was observed in 25/102 (24.5%) participants with no participant recording a 4AT score greater than three. Spearman’s rank correlation coefficient demonstrated that increasing age was associated with longer dCDT time for both command and copy dCDT conditions ($r = 0.22$ $p = 0.024$; $r = 0.20$, $p = 0.046$ respectively). Lower years of education was associated with longer dCDT times for both command and copy clocks ($r = -0.39$ $p < 0.001$; $r = -0.25$, $p = 0.011$) respectively.

Next we compared the dCDT clock performance of people with a 4AT score of >0 to those with a 4AT score of <0. Command and copy clock scores were significantly lower in those with 4AT > 0 compared with 4AT = 0. Likewise, copy dCDT *time* was significantly longer in those with 4AT > 0 compared with 4AT = 0, however in the command condition, dCDT time did not differ between those with 4AT > 0 and 4AT = 0 (Table 3).

To examine the impact of extraneous variables on dCDT command and copy clock performance for dCDT time and clock score, we performed multivariable linear regression and logistic regression respectively. We entered age, sex, education, prior tablet use and 4AT score into these models. In both command and copy conditions, prior use of touch screen devices was not associated with dCDT time nor clock score (Table 4 and Table 5). In contrast, years of education and 4AT score were significant predictors of dCDT *time* for both command and copy conditions (but not dCDT *score*).

Discussion

The present study aimed to assess the feasibility and validity of the dCDT in testing older adults in the perioperative setting. Feasibility and acceptability was established with 99% of patients undertaking and completing the dCDT task. The dCDT was aligned with feasibility recommendations making it feasible for cognitive screening in day of surgery admission patients.³¹ The tool was highly acceptable to people aged 65 years or more presenting for elective surgery regardless of prior tablet experience. Approximately one third of older adults (35%) recruited to this study had minimal prior tablet use (less than an hour per week), however our findings suggest that this limited experience did not affect test performance, consistent with prior research.²⁴ Validity was suggested by a robust relationship between the dCDT time and clock scores with the 4AT. Our results indicate that longer dCDT times and lower clock scores are sensitive to cognitive impairment in the older adult surgical population. On balance, our findings support the dCDT as a screening tool for cognitive impairment in perioperative settings.

The dCDT in this study is an improvement on paper-based tools and current commercial versions of stand-alone digitised pens, which are single purpose, bulky to draw with and require ink and paper. By using a tablet display and stylus this new tablet-based dCDT provides immediate feedback to the user about dCDT metrics without requiring an external computer. In this study the dCDT took ~ 2 minutes to complete and was faster than other perioperative tablet-based applications for screening cognition.^{27,37} Finally, a distinct advantage of the dCDT compared to paper-based tests is its potential for integration with electronic medical records.

The acceptance rate reported here was reinforced by qualitative feedback from participants who described their experience with the tablet as 'fun' and 'enjoyable'. The brief questions, short duration of the test and familiarity with the shape of the digitised pencil (rather than direct finger to tablet), may explain why the uptake of the test was higher compared to other perioperative tablet-based studies that had rejection rates as high as 35%.³⁸

The design of the tablet-based dCDT application was appropriate for the clinical environment. There were no software failures and no omission of data points related to human error. The usability of the dCDT could be further improved through the implementation of in-app voiceover/text instructions for the command and in-app clock image for the copy clock condition of the dCDT to minimise personnel requirements and minimise confounding effects of sensory impairments. For infection control, the tablet device was used in a sealed cover which withstood over one hundred wipes with 70% isopropyl alcohol surface cleaner without malfunction, as expected based on the manufacturers disinfectant protocol.³⁹ An unexpected positive finding from this study was the flexibility in test administration that the dCDT enabled; participants were able to perform the test at the

nurse check in station, lying supine or whilst standing. This makes the dCDT suitable for bedside assessments and is an advantage over the standard pen on paper test because lower limits of pen pressure are required to create an image on the digitised surface and an additional firm surface is not required.

Importantly in this sample, prior tablet use was not associated with dCDT time or clock scores. This is consistent with work by Fazeli et al, who reported that prior computer experience did not influence performance on computerised tests. Moreover, the majority (65%) of participants were prior touch screen users.²⁴ Interestingly, age was not associated with dCDT copy performance, suggesting that the dCDT may be a suitable screening tool for older people spanning multiple decades. In contrast, less years of education was associated with poorer dCDT performance. This is an important caveat and education must be taken into account to correctly interpret screening test results in the clinical setting.

Our results contribute to ongoing work to determine the clinical utility of dCDT variables in screening cognitive impairment in the perioperative period. Our findings are consistent with previous work, supporting the notion that dCDT time is associated with cognitive impairment.^{22,40,41}

This study has limitations that may affect its generalisability. First, we compared the sensitivity of the dCDT to a simple cognitive screening tool (i.e., the 4AT) and did not include a comprehensive neuropsychological test battery. We are therefore unable to make conclusions about the specific cognitive domains that the dCDT captured or how these domains relate to broader neurocognitive disorders in the perioperative population. A broader neuropsychological examination of cognitive domains would allow for a more comprehensive interpretation of the dCDT results, but this lay outside the scope of the present study. To reduce administration burden in the perioperative environment, we developed the tablet-based dCDT to record clock drawing time from the moment the pen connected with the digitised surface. As a result, time spent planning after the delivery of test instructions but before commencing clock drawing was not calculated. Although this was not a variable of interest in the present study, planning time is a metric of interest for some clinicians and may be considered for future iterations of the dCDT. Ninety-one eligible participants were not approached in this study because there was only a single assessor and one device. In terms of the study population we did not collect formal data pertaining to ethnicity or socioeconomic status, however the appropriateness of the dCDT across diverse populations should be a focus of future research. Moreover, we did not account for levels of depression, anxiety or pain. These psychological variables are known to have transient effects on cognition⁴² and may have had an influence on participant performance, particularly in the immediate preoperative period. Future research may seek to address the impact of transient psychological states of dCDT performance in the perioperative period.

Conclusion

The dCDT is feasible for the perioperative environment and demonstrates convergent validity with the 4AT. This study showed a positive uptake of the dCDT amongst patients, which was in contrast to other cognitive screening and tablet-based tools.^{17,38} Alongside a high level of acceptability, the dCDT has several advantages over paper based screening tools, including the ability to transfer information readily to online medical records, making it appropriate for use in busy perioperative hospital settings, and the minimal training required of staff to administer the test. Given the practicality of the tool, it may prove a useful addition to facilitate routine cognitive screening in clinical practice.

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Conflict of Interest

None to declare.

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Figure legend:

Figure 1: Participant eligibility, sources and methods of selection.

Table 1. Participant Characteristics. Values are number (proportion), mean (SD)

	N = 102
Age (years)	74.4 (6.7)
Sex (M)	52 (51%)
Education (years)	11.7 (5.6)
Handedness (R)	91 (89%)
Prior tablet use (Y)	66 (65%)
4AT total score	
4AT = 0 *	77 (75%)
4AT > 0	25 (25%)
MoCA Clock scores	
Command > 1 *	74 (73%)
Copy > 1*	93 (96%)

Data are presented as mean $\pm$ standard deviation or n (%).

Abbreviations: 4AT, 4 A's Test, SD, standard deviation.

* Defined as normal cognition

Table 2. Key areas for the feasibility of the dCDT

	Questions for investigators to determine feasibility:	Outcomes observed:
Acceptability	Do participants complete the task in its entirety? Do participants spontaneously express satisfaction with the dCDT?	Patients continued to completion of task. Patients expressed satisfaction at completing the task.
Demand	Is the dCDT likely to be used?	Demand for a quick, easy screening tool is high. Patients reacted positively to the use of this tool.
Implementation	Can the dCDT be delivered to intended participants?	We have demonstrated this tool can be effectively delivered to older adults in the preoperative setting regardless of prior tablet use.

Feasibility of a digital clock test

Practicality	Can the dCDT be delivered in a clinical environment?	The device is portable, light weight, able and was effectively sterilised without damage.
Adaptation	Does the dCDT perform when used in different environments?	The tablet device can be used on multiple surfaces, while the patient is sitting in a chair or in a bed.
Integration	Can the dCDT be integrated with existing systems?	The outputs of the application can be easily forwarded to other computers or software systems. This includes via screenshots, videos and data of dCDT metrics.
Expansion	To what extent can the dCDT be improved?	The tablet used is multifunctional and already houses medical record software. Future developments could allow the software to connect with the dCDT. The program on the tablet could implement voice commands to assist linguistically diverse groups without the need for an interpreter. This may also assist out of hospital administration. The program could contain a pre-drawn clock to assist the copy condition.
Efficacy testing	Does the dCDT show promise of being useful for the elderly perioperative population?	We have shown some early data that the outputs of the dCDT have convergent validity with the 4AT. Further analysis of the how dCDT metrics correlate to neuropsychological testing is required. Furthermore, longitudinal analysis of dCDT variables over time are underway and may provide other insights into cognition.

Table 3. Wilcoxon Rank Sum test between 4AT groups (4AT = 0, 4AT > 0).

4AT = 0 (n = 77)

4AT > 0 (n = 25)

	Median (IQR [range])	Median (IQR [range])	<i>p</i> – value
Command			
dCDT Time (s)	32 (26 – 39 [14 – 85])	37 (26 -55 [15 – 107])	0.092
Clock Score	2 (2-2 [1 – 3])	2 (1-2 [0 – 3])	<0.001
Copy			
dCDT Time (s)	29 (24 – 35 [18 – 118])	41 (31 – 53 [17 – 120])	0.002
Clock score	2 (2 – 3 [1-3])	2 (2-3 [1-3])	0.038

Abbreviations: 4AT, 4 A's Test, IQR, interquartile range, dCDT, digital clock drawing test.

Table 4. Linear regression assessing variables association with dCDT time. CI, Confidence interval.

	Command Clock dCDT Time		Copy Clock dCDT Time	
Predictors	β [95% CI]	<i>p</i> -value	β [95% CI]	<i>p</i> -value
Prior tablet use ^a	-.29 [-6.9, 6.3]	0.931	.43 [-7.2, 8.1]	0.911
Age (years)	.27 [-.01, .56]	0.061	.39 [-.15, .93]	0.155
Education (years)	-.75 [-1.3, -.20]	0.009	-.81 [-1.5, -.15]	0.016
Sex (F)	-1.4 [-7.3, 4.6]	0.653	6.6 [-.30, 14]	0.060
4AT (= 0)	8.2 [1.3, 15]	0.020	12 [3.7, 19]	0.005

^a Dichotomous yes/no variable

Abbreviations: dCDT, digital clock drawing test, CI, Confidence interval, β , Beta coefficient, 4AT, 4 A's Test.

Table 5. Logistic regression assessing variables association with clock score. CI, Confidence interval.

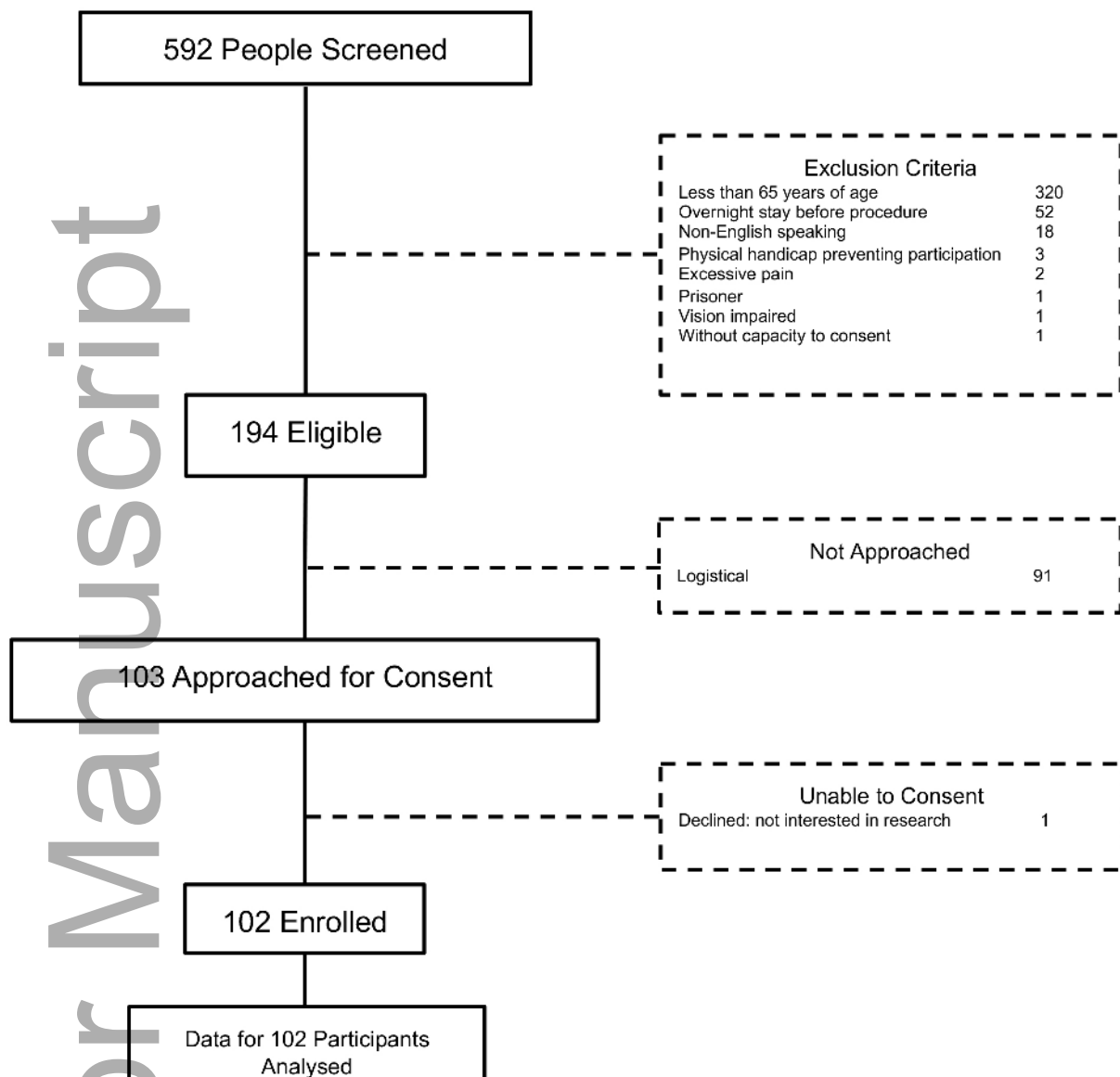
	Command Clock Clock score > 1		Copy Clock Clock score > 1	
Predictors	OR [95% CI]	<i>p</i> -value	OR [95% CI]	<i>p</i> -value

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Prior tablet use ^a	1.5 [.52, 4.1]	0.475	2.8 [.55, 14]	0.217
Age (years)	.98 [.93, 1.0]	0.521	.94 [.84, 1.1]	0.300
Education (years)	1.1 [.96, 1.2]	0.244	1.0 [.90, 1.2]	0.570
Sex (F)	1.0 [.38, 2.8]	0.963	.65 [.13, 3.2]	0.589
4AT (= 0)	.19 [.068, .53]	0.001	.14 [.031, .66]	0.012

^a Dichotomous yes/no variable

Abbreviations: dCDT, digital clock drawing test, CI, Confidence interval, OR, odds ratio, 4AT, 4 A's Test.



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