Young, Z., Craven, M. P., Groom, M., Crowe, J. (2014) Snappy App: a mobile continuous performance test with physical activity measurement for assessing Attention Deficit Hyperactivity Disorder. In Kurosu, M. (ed.) Human-Computer Interaction. Applications and Services, Lecture Notes in Computer Science, Vol. 8512, HCII 2014, Part III, Springer, pp. 363-373. Doi:10.1007/978-3-319-07227-2_35 Available at: http://link.springer.com/chapter/10.1007/978-3-319-07227-2_35

Snappy App: a mobile continuous performance test with physical activity measurement for assessing Attention Deficit Hyperactivity Disorder

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Abstract. A Continuous Performance Test (CPT) was incorporated into a smartphone application (App) to measure three symptom domains associated with Attention Deficit Hyperactivity Disorder (ADHD); attention, impulsivity and hyperactivity. The App was pilot tested on 11 healthy adults over three testing sessions. No differences in performance were found between testing sessions suggesting good test consistency. A decrement in performance over time was only found for one measure of attention and on one testing session. The CPT showed some sensitivity to ADHD-related symptoms where self-reported impulsive behaviour was related to the CPT measures of impulsivity and activity. User acceptability was good although some design improvements were suggested. Further pilot testing of the App in a clinical population is needed.

Keywords: Attention Deficit Hyperactivity Disorder, Continuous Performance Test, m-Health, Ecological interfaces, New technology and its usefulness, Psychological application for user interface, Qualitative and quantitative measurement and evaluation

1 Background

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental syndrome that is characterised by three core behaviours; inattention, hyperactivity and impulsivity and often persists into adulthood [1,2,3]. It is typically thought that between 3 and 5% of school aged children have the disorder (National Institute for Health and Clinical Excellence) [4].

It has been suggested that ADHD stems from multiple causes, such as genetics, biological and psychosocial influences [5], and results in a range of pathological behaviours [6,7]. There is no single gene that is considered to underpin ADHD. Instead, it is thought to arise from the combination of multiple genes, each gene having a small effect [5,8]. ADHD often overlaps with other disorders and can have negative long-term consequences including increased risk of school failure, unemployment and mental health difficulties [1, 9].

Given the variation in symptoms and behavioural consequences of ADHD, diagnosis, symptom monitoring and response to medication often relies on subjective interpretation of information gained through clinical interview and standardised rating scales. More recently, psychometric tests are used in the assessment process to provide objective measures of patient's symptoms. Such measures of cognitive function also offer the potential to objectively measure response to medication, and could potentially hasten the process of treatment optimisation [10].

One such standardised test is the continuous performance test (CPT) which is a neuropsychological test that measures attention and impulsivity during a sustained task. Typically, a CPT is a computer based programme which involves rapid presentation of visual or auditory stimuli. Participants are asked to respond when a given target occurs but remain passive to non-targets [11]. A commonly used CPT is one where a sequence of letters is displayed such that a response is required for a display of the letter X only after the letter A (visual AX-CPT). Missing responses (Omission Errors), incorrect responses (Commission Errors) and reaction time (RT) are recorded. This CPT is preferable to using the X-CPT in adults where ceiling effects are often found [2]. These kinds of objective tests are commonly used to assess attention [10] and are considered to be the most sensitive assessment of medication effects [12]. Studies have shown a clear separation on CPTs between people with ADHD and controls, with ADHD participants showing poorer performance on measures of attention and impulsivity [13,14]. Nevertheless, controversy remains as to whether CPTs are capable of distinguishing between ADHD and other disorders [2].

Hyperactivity is one of the core symptoms of ADHD and is usually measured by subjective standardised rating scales. Some objective measures of attention now incorporate motor activity measures using actigraphs [15] or infra-red motion analysis [10,16,17] to give a fuller picture of the range of symptoms associated with ADHD. Such cognitive tests with motion analysis can reliably differentiate children [10,17] and adults with ADHD [3] from controls and can provide a good measure of treatment response, with the potential for speeding up treatment optimisation [10].

Such measures are confined to clinic visits, which are time consuming and costly, therefore a cost effective way of remotely and objectively monitoring symptoms without patients having to attend clinic would be useful. The aim of this pilot study is to see whether a CPT can be incorporated into a smartphone application whilst also measuring motion activity throughout the course of the task.

With the recent rise in the use of smartphones and the advances in technology, mobile software applications (Apps) are now being used in healthcare. Although software applications with relevant features are available on other devices such as personal computers and laptops, smartphones (and some smaller tablets) have the advantage of being portable and are more often than not in the owner's possession. This allows the user to stay in touch with people (whether they be friends, family or healthcare professionals) and access information or receive support via the internet at any time of day and from virtually any location [18]. Smartphones are now the second most popular device for accessing the internet, second only to laptops [19].

The concept of using Apps in mental health is relatively new so many available products have not yet been researched experimentally. In general, the regulatory environment for Apps is in development (e.g. FDA guidance in the USA was finalised in September 2013). In England, a recent review of the NHS Choices apps library was been focussed on safety, and consequently there is still little information regarding reliability and validity of the content of most Apps currently on the market. Available Apps for ADHD range from those that give information about the diagnosis and treatment of ADHD, to various ADHD tests, task management and reminders. There is a huge variety in the content of Apps for ADHD with a limited number having been produced by, or in consultation with, healthcare professionals. And even fewer have been researched experimentally [20].

In the current pilot study the AX-CPT test has been incorporated into a smartphone application for Android phones and subsequently as a web App that also runs on other platforms (e.g. iPhone). In addition to the CPT, the App captures 3-Dimensional movement data from accelerometer and gyroscope sensors in the phone (if present). This data is used to measure the amount of physical activity during the course of the CPT, measured by the amount the phone moves. The test combined with the sensor readings therefore provides information on each of the three ADHD behaviours (attention, impulsivity and hyperactivity). Following data capture, mean Omission Errors and Commission Errors, mean Reaction Time (RT) and standard deviation of RT (RT variability) on the CPT is analysed to provide an index of sustained attention (Omission Errors, RT, RT variability and changes in these over the course of the task) and impulse control (Commission Errors). Activity across different time sections of the task is also analysed. This data can then be used to establish whether it may be possible to extract a meaningful and reliable measurement of activity in a clinical population sample.

Subjectively measured impulsivity is measured and compared with performance on the CPT, to determine whether the test is sensitive to variation in these ADHD-related traits in healthy individuals. It is known that these behaviours vary in the general population and that ADHD is at the extreme end of this continuum. The purpose of the study was to pilot the App in the general (non-clinical) population.

2 Method

Participants

Participants were students and staff from the University of Nottingham (N=11, 1 male). All participants visited the Division of Psychiatry and Applied Psychology, University of Nottingham, where they completed a practice version of the AX-CPT on their own smartphone under the supervision of a researcher. Each participant completed the full task three or four times when prompted by the App (over a period of 10-14 days).

Software

The App to implement the visual CPT-AX test was initially designed using the Eclipse IDE (Integrated Development Environment) for Java developers, for an Android platform with an operating system v2.2 and above. The alarm function on the phone was employed to prompt users to take the test at predetermined times. Subsequently a web App was developed in JavaScript to implement the same functions (except without the Alarm). Fig. 1 shows a screenshot of the App (Android version).

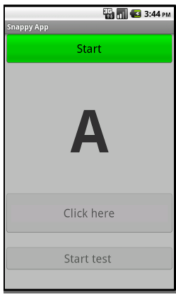

Fig. 1. Snappy App screenshot, Android smartphone implementation

Measures

Continuous Performance Test (CPT). A set of sequences containing the correct statistics for the AX-CPT were encoded to be presented in a pseudo-random manner. Within each sequence, presentation probabilities were p(A)=0.2 and p(X)=0.2 of which 50% follow A, p(H)=0.2 of which 50% follow A, and 8 other letters (B, C, D, E, F, G, J, L) with p=0.05. The website *random.org* was used to create a randomised sequence of numbers that were then assigned to the letters and AX pairs, with manual swaps where necessary to avoid creation of additional AX pairs.

Letters were presented at 1.65 second intervals with a duration of 150 milliseconds (ms), and the same presentation of 100 letters was presented four times resulting in a test lasting a total of 11 minutes, similar to the protocol of van Leeuwen et al. [11]. Sensor data was collected asynchronously down to 0.01 second intervals but the number of samples was dependant on sufficient movement of the phone. Accelerometer data including gravity was captured for each of the X, Y, Z axes (in units of m/s^2) and gyroscope orientation data for each of the Alpha, Beta and Gamma angles (in degrees) to give a measure of Activity.

CPT test and sensor data was captured for each of the 400 presentations of the letter sequence (over the 11 minutes) and, as well as recording the raw sensor data, the sums of clicks and errors from the CPT were computed for each of the four time segments and the mean and sample standard deviation was computed for RT and for the magnitudes of the accelerometer and gyroscope sensor readings for each of the same four time segments (samples of which were first averaged over the presentation period). This computation within the App was performed to speed up the analysis, although it was also possible to return to the raw data if required.

UPPS-P Impulsive Behaviour Scale. Impulsive-type behaviour was measured by the UPPS-P scale [21, 22]; a 59-item self-report questionnaire that assesses five subscales (Negative Urgency, (lack of) Premeditation, (lack of) Perseverance, Sensation

Seeking, and Positive Urgency) in adolescents and adults (age 12 and up) in the general population. Participants are asked to answer the questions based on their experiences over the last six months and rate their behaviour and attitudes on a 4-point scale (1=Agree strongly to 4=Disagree strongly). The questionnaire gives a total impulsivity score plus a score for each of the five subscales. In order to put each subscale into the same metric, mean scores are calculated for the items on each subscale, from 1 to 4, where 1 indicates a low level of self-reported impulsivity and 4 indicates a high level. Negative Urgency refers to the tendency to experience strong impulses under conditions of negative affect. Positive Urgency refers to the tendency toward rash action in response to very positive mood. (Lack of) Premeditation is the tendency to fail to think and reflect on the consequences of an act before engaging in that act. (Lack of) Perseverance reflects difficulties remaining focused on a task that may be long, boring, or difficult. Sensation Seeking encompasses two aspects: the tendency to enjoy and pursue exciting activities and openness to trying new experiences.

Participant feedback questionnaire. Participants were asked to rate the App on a number of features in order to feed into further amendments to the App design in preparation for a clinical study. The questionnaire aims to determine whether participants found the task accessible and to seek suggestions to improve the task through eight items: four of which should be answered on a 5-point scale (1=Strongly agree to 5=Strongly disagree), two of which are option boxes and the final two are free text.

3 Results

Descriptive data is shown in Table 1. Mean Omission Errors, Commission Errors, RT, RT variability and Activity (from Accelerometer and Gyroscope data) were calculated across participants for each testing session. Scores were also collapsed over the three tests to give an overall mean for each CPT measure. Activity data was not available for all participants so this measure was analysed separately.

Table 1. Sample characteristics for age, CPT measures and UPPS-P Impulsive Behaviour Scale including effects of testing session on CPT performance

	Overall	Test 1	Test 2	Test 3	*F*	*p*
N	11	11	11	11		
Sex (male/female)	1/10	1/10	1/10	1/10		
Age	34.03 ± 8.35	34.03 ± 8.35	34.03 ± 8.35	34.03 ± 8.35		
CPT						
Omission Errors	0.53 ± 0.48	0.45 ± 0.37	0.50 ± 0.43	0.64 ± 0.80	0.70	.51
Commission Errors	0.58 ± 0.93	0.41 ± 0.65	0.70 ± 1.01	0.61 ± 1.23	1.41	.27
Reaction Time *(ms)*	525.46 ± 94.88	524.37 ± 88.43	529.93 ± 101.69	522.07 ± 103.02	.20	.82
Reaction Time Variability *(ms)*	38.67 ± 12.71	32.28 ± 9.90	38.85 ± 23.77	44.87 ± 26.19	1.01	.38
Accelerometer (n=6)	10.57 ± 1.62	10.73 ± 1.99	10.46 ± 1.33	10.53 ± 1.53	1.08	.38
Gyroscope (n=4)	86.87 ± 38.58	61.24 ± 44.98	111.29 ± 65.66	88.06 ± 37.92	1.52	.29
UPPS-P Total	123.27 ± 20.12					
Negative Urgency	2.18 ± 0.74					
Premeditation	2.03 ± 0.33					
Perseverance	1.88 ± 0.38					
Sensation Seeking	2.64 ± 0.61					
Positive Urgency	1.73 ± 0.64					

±(standard deviations) All *p* values are non-significant

Differences between testing sessions

To see whether there was a difference in performance on the CPT between test sessions on each of the factors (Omission Errors, Commission Errors, RT and RT variability), a mixed design ANOVA with test session as the within subjects factor was conducted. No main effect of test session was found for any measure (all $p > .05$) suggesting that there were no practice or deterioration effects between test sessions.

Analysis of time on task measures

Mean Omission Errors, Commission Errors, RT and RT variability were calculated for each of the three tests and each test was broken into the four time periods of 100 letter presentations (TP) in order to compare performance patterns over time. We looked at the four TP for the factors; Omission Errors, Commission Errors, RT and RT variability by running a series of 1x4 mixed design ANOVA with TP as the within subject factor and repeated for each of the 3 tests. No main effect of TP was found for any measure on Test 1 or Test 2 (all $p > .05$) indicating that there were no changes in performance over time. A main effect of TP on Omission Errors was found for Test 3 only [F (3, 10) = 4.02, $p < .05$]. This effect was explored further and a linear pattern was found for Omission Errors, i.e. a decrement in performance during the course of the task, reflected in increased Omission Errors from TP 1 through 4 [F (1, 10) = 6.41, $p < .05$], with the significant difference being between TP 1 and TP 3 ($p < .05$).

Activity

Activity data were captured for four out of 11 participants due to their mobile phones having this capability. Two gave accelerometer data and four gave both accelerometer and gyroscope data. Activity levels were ultimately measured by taking the mean activity level in specific time windows using the accelerometer data only, due to the gyroscope data not readily providing a meaningful mean score for the purposes of this analysis (due to inconsistent transitions from ~0 to ~360 degrees) and also since a minority of the phones produced this data. Corrections were not made for movements triggered by making a response to the target stimulus, since these movements were of short duration compared to the presentation time period over which the mean was calculated. Activity was compared separately due to the different number of participants providing this. Activity levels were compared between test sessions by way of a 1x3 mixed design ANOVA with test session as the within subject factor. No main effect of test session was found ($p > .05$) suggesting participants' motor activity was consistent across testing sessions. Activity levels were also compared during the course of each test session by a series of 1x4 mixed design ANOVAs with TP as the within subjects factor. This was repeated for each of the 3 test sessions. No main effect of TP was found on any test session (all $p > .05$) indicating that motor activity during the course of each test was consistent.

Symptom ratings

Correlations were calculated to determine whether the test is sensitive to variation in subjectively rated impulsive behaviour traits (Table 2). Mean scores were used for each of the five UPPS-P subscales and overall mean was used for Omission Errors, Commission Errors, RT, RT variability and Activity. Significant correlations were found between Commission Errors and one UPPS-P subscale: (Lack of) Perseverance (r= .84 n= 11 *p*= .001). Activity was significantly correlated with Positive Urgency (r=.86 n=11 p< .05). Omission Errors were significantly correlated with RT variability (r= .74 n= 11 *p*< .01) and as expected RT was significantly correlated with RT variability (r= .79 n=11 *p*< .01) (Table 3).

Table 2. Correlations between the CPT measures and UPPS-P Impulsive Behaviour Scale

	UPPS Total	Negative Urgency	Premeditation	Perserverance	Sensation Seeking	Positive Urgency
Omission	.133	.270	.024	.392	-.498	.261
Commission	.474	.539	-.436	.839**	-.162	.482
RT	-.291	-.146	-.294	-.147	-.197	-.166
RT variability	.201	.321	-.271	.244	-.151	.263
Activity	.769	.769	-.153	.753	.183	.835*

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlations between the CPT measures

	Omission	Commission	RT	RT variability	Activity
Omission	--				
Commission	.273	--			
RT	.556	-.204	--		
RT variability	.742**	.138	.793**	--	
Activity	.527	-.322	.382	.237	--

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Participant feedback

A summary of the participant feedback questionnaires found that:

- 11/11 participants found the task easy.
- 6/11 found the phone comfortable to hold whist doing the task (4/11 were neutral).
- 8/11 participants did not find the task stressful.
- 10/11 participants reported that they were asked to complete the task at a convenient time.
- 5/11 participants would prefer to complete the task between 11am and 1pm.

A summary of suggestions for improvements to the task were as follows:

- Replace the white screen with a coloured one.
- Provide a scoring or ranking system.
- Make the letters a larger font size.
- Provide help options.
- Choose own username.
- Text reminder after an hour if the task hasn't yet been completed.
- Ensure the time is not visible on the screen of the phone whilst completing the task.

4 Discussion

Attention, impulsivity and activity levels were consistent across testing sessions suggesting there were no effects of practice or deterioration across testing sessions. One measure of attention; Omission Errors varied over time on Test 3 only, indicating a decrement in performance over time. Further testing sessions with a larger sample are needed to determine whether this waning of attention is due to familiarity with the task as this effect was only evident in Test 3. All other performance measures remained consistent over the course of each test session. Differences in performance over time were not expected in the current sample since previous research has found no effects of time on task for healthy participants. However, decrements in performance over time are seen in ADHD participants on RT variability and Commission Errors [e.g. 16, 23].

The CPT showed some sensitivity to ADHD-related traits in healthy individuals. Subjective symptom ratings were compared with the CPT measures to find that Commission Errors were correlated with (lack of) Perseverance, suggesting that the CPT is successfully measuring one aspect of impulsive behaviour. Activity levels were correlated with Positive Urgency suggesting that the CPT is reflecting hyperactive-impulsive behaviour. Interestingly, Omission Errors and RT were the only CPT measures that were correlated (except for RT and RT variability which we would expect to be highly correlated). As both of these measures are thought to reflect attention we would also expect them to be correlated if the task is successfully measuring attention. The finding that RT was not related to any of the symptom ratings is consistent with previous research findings where the variability of RT over time seems to be a much more robust measure [23]. These findings have implications for future App development, and if shown to be a sensitive measure of ADHD symptoms, could prove to be a cost-effective and portable adjunct to clinical assessment.

Overall, participants rated their experience of using the App positively. In future studies, gathering feedback from a clinical sample will determine whether their user experiences differ.

Limitations

Activity measures were only available for 6 out of the 11 participants due to their phones not having accelerometer capabilities. With such a small sample of activity data it is difficult to draw any conclusions about activity levels. However along with the correlation between Activity and Negative Urgency, trends toward a significant correlation were found between Activity and two of the UPPS-P impulsivity measures (UPPS-P Total score and Negative Urgency). It is possible that with more participants statistically significant relationships could be found for objectively measured activity levels and subjectively rated ADHD-related symptoms. We must however note that UPPS is used for a measure of impulsivity, one element of ADHD, but that its validity and reliability as a measure of ADHD signs/symptoms is yet to be properly established.

This sample was drawn from a University so is restricted to University staff and students. This could potentially limit the variability in results. For the purposes of pilot testing the App this is not a significant concern, however if the App is further tested, a more diverse sample should be used. The sample also had many more female than male participants, which again should be rectified on further testing of the App to avoid any gender bias in the results.

Future work will take participant feedback into account to make improvements on the current App. Attempts will be made to provide a summary score for overall performance on the test and for each symptom domain; attention, impulsivity and hyperactivity. We will then seek to test the App in a clinical population of both children and adults, alongside a larger normative comparison group. Since CPTs are considered to be the most sensitive assessment of medication effects [12], there is potential for this App to be used remotely to monitor changes in ADHD symptoms while practitioners are initiating treatment. This could provide practitioners with more information regarding patient's symptoms and medication efficacy. Only through testing in a clinical sample can we determine whether the App is sensitive to ADHD symptoms.

5 Acknowledgements

The research reported in this paper was conducted by the National Institute for Health Research MindTech Healthcare Technology Co-operative (NIHR MindTech HTC) and funded by the NIHR. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health. MC and JC acknowledge additional support for the App development work through the Multidisciplinary Assessment of Technology for Healthcare (MATCH) programme (EPSRC Grant EP/F063822/1). The authors also wish to acknowledge the valuable input of other collaborators in both MindTech and MATCH during the Snappy App development.

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