DUAL TASK PERFORMANCE AND PRIORITIZATION
IN PARKINSON’S DISEASE AND HEALTHY ELDERLY INDIVIDUALS:
ANALYSIS OF A NOVEL ASSESSMENT WITH INCREASING COMPLEXITY

by

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ABSTRACT

DUAL TASK PERFORMANCE AND PRIORITIZATION IN PARKINSON’S DISEASE AND HEALTHY ELDERLY INDIVIDUALS: ANALYSIS OF A NOVEL ASSESSMENT WITH INCREASING COMPLEXITY

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Background. The Clinch Token Transfer Test (C3t) is a seated assessment combining a bimanual coin transfer and manipulation task with a secondary cognitive task under three levels of complexity. Aims. The six aims of this study were to determine if: 1 & 2) the C3t was a reliable and valid measure of manual dexterity and dual task ability in PwPD; 3 & 6) C3t performance or movement component parameters differed between healthy controls and PwPD and were sensitive to disease severity; 4) baseline assessments were predictors of C3t performance, and 5) DT prioritization differed between the C3t and Timed Up & Go tests. Methods. Thirty-nine participants were selected and placed into three groups: 1) mild PD (Hoehn & Yahr (H&Y)=I) (n=13); 2) mod PD (H&Y=II or III) (n=13); 3) healthy controls (HC) who were age, gender and education matched to mild PD (n=13). During session 1 participants completed a battery of cognitive and motor assessments including the C3t and TUG. PwPD returned for a second C3t assessment. Results. The C3t demonstrated good test re-test reliability for baseline and complex but poor reliability for DT conditions; construct validity as a manual dexterity measure was established with the 9-Hole Peg Test. Significant C3t performance differences were seen between: 1) mod PD and HC on all task conditions; and 3) between mild and mod PD on baseline and complex conditions. Regression analysis indicated hand dexterity and Stroop tests were performance predictors on the less complex C3t tasks. Task
prioritization patterns differed between the C3t and TUG dual task conditions. On the C3t, PwPD and HC demonstrated a prioritization pattern of mutual interference while demonstrating varied patterns of cost/benefit on the DT TUG. Movement component analysis revealed time differences in four components between mod PD and HC.

**Conclusions.** The C3t is a reliable and valid manual-dexterity assessment in PwPD. All C3t task scores differentiated between PwPD and HC. Baseline and complex scores were sensitive to disease severity, differentiating between mild PD and mod PD. The C3t DT condition was not found to be reliable requiring further development and additional evaluation prior to implementation.
I dedicate this dissertation to two extraordinary renaissance women who have enhanced my life in many ways. Ann Gentile who started this…and Lori Quinn who finished it.
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A journey of 29 years and 5 months cannot be accomplished alone. I am grateful for each and every individual along the way who opened doors, supported my efforts, offered me words of encouragement, taught me something new, gave me a shoulder to cry on, set me straight or helped to put things into perspective.

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making them excellent clinicians. As a dear friend, we shared the major accomplishments and daily happenings each other’s lives. It is a testament to her professionalism that she agreed to become my advisor, knowing that she would have to be tough and critical and push me. She has taught me so much and it makes this accomplishment that much sweeter because it is something else we have shared.

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Chapter I
INTRODUCTION

Parkinson’s Disease

Parkinson’s disease (PD) is a chronic, progressive, neurodegenerative disease characterized by a loss of dopaminergic cells from the pars compacta of the substantia nigra (Lees, Hardy, & Revesz, 2009). This loss of dopamine and progressive cell loss cause motor impairments including bradykinesia, tremor and rigidity, resulting in impairments with balance, gait, and manual dexterity (Magrinelli et al., 2016). The basal ganglia (including the substantia nigra) circuitry plays a key role in movement planning and execution, however, the basal ganglia participate in other functions including learning, planning, executive functions and emotions. As a result, PD, was once thought to be a pure motor disease, but is now known to include a variety of non-motor and cognitive symptoms (Magrinelli et al., 2016). Four parallel functional loops involving the basal ganglia – cortical – thalamic circuitry (motor, oculomotor, associative and limbic loops), have been identified (Magrinelli et al., 2016). Of interest to this study are the associative or prefrontal loop, which plays a role in executive dysfunction and the motor loop, playing a role in program selection, motor learning, movement planning and execution (Magrinelli et al., 2016; Purves et al., 2017). A consequence of the PD motor deficits is decreased movement automaticity, where individuals require increased attentional resources to initiate and execute motor skills that were once automatic (Gilat et al., 2017; Wu, Hallett, & Chan, 2015).
People with PD (PwPD) also may experience difficulties in executive functioning and present with impaired decision making, planning, problem solving, task/set switching and inhibition (Dirnberger & Jahanshahi, 2013). Due to loss of automaticity, a larger proportion of attentional resources must be allocated to movement execution thereby making it more difficult for PwPD to successfully perform two activities simultaneously. People with Parkinson’s disease (PwPD) also have reduced control of attention, evidenced by difficulty switching between tasks (task switching) or rules (set-shifting) (Woodward, Bub, & Hunter, 2002) and flexibly shifting their attention between tasks (Rustamov et al., 2014; Sawada et al., 2012). Task switching requires an individual to rapidly alternate between different courses of thought and action (Logan & Schneider, 2006) as well as preparing and maintaining two task sets (Koch, Poljac, Müller, & Kiesel, 2018a). Cognitive set-shifting involves the ability to switch styles of thinking, strategies or perspectives in order to adapt to changing environmental demands or task specifications (Lange, Seer, & Kopp, 2017). Specific tests have been designed to evaluate set-shifting ability, most commonly the Wisconsin Card Sorting Test, where participants need to sort cards by identifying task rules (Anderson, Damasio, Jones, & Tranel, 1991); and the Trail Making Test B, requiring participants to draw a continuous line that alternates between connecting numbers and letters as quickly as possible (Sánchez-Cubillo et al., 2009).

**Upper Extremity Function and Assessment in PD**

The motor deficits in PD influence not only the trunk and lower extremities leading to posture and walking deficits, but also impact upper extremity function, which can affect work, recreation and many activities of daily living. The speed, coordination, fluency and efficiency of upper extremity gross and fine motor coordination are often impaired in PD, and PwPD describe difficulty manipulating objects with adequate speed
and dexterity (Haaxma, Bloem, Overeem, Borm, & Horstink, 2010; Sturkenboom et al., 2011). Small handwriting, known as micrographia, is often one of the first symptoms identified by PwPD. Standardized assessment measures for upper extremity function, including handwriting in PwPD are very limited (Proud et al., 2015). Proud et al. (2015) reviewed measures of upper limb function in PwPD and found that most assessments described the presence or severity of an impairment (e.g. rigidity) but with little evidence to support their relationship to function. Seven generic manual dexterity assessments were identified. Proud and colleagues concluded that their review, “highlights the lack of quality evidence available to guide clinicians and researchers in the selection of measurement tools to evaluate change in upper limb impairments, activity limitations and associated participation restriction in people with PD” (Proud et al., 2015).

To address this limitation in upper extremity functional assessments targeting individuals with neurodegenerative diseases, Clinch (2017) created the initial version of the C3t (the Moneybox Test) as a dual task assessment of upper limb functional activities in the Huntington’s disease (HD) population. The C3t combines performance of a functional, bi-manual, coin-manipulation task with a cognitive task in conditions of increasing complexity. Clinch designed the C3t to target motor and cognitive functions involving the impaired cortico-basal ganglia circuitry seen in HD pathology. She chose manual dexterity as the target task included to evaluate degeneration of the basal ganglia motor loop (Clinch, 2017; Opara, Malecki, Malecka, & Socha, 2017) and used a dual tasking paradigm to assess the executive dysfunction deficits noted to accompany associative loop degeneration in PwPD (Dirnberger & Jahanshahi, 2013).

**Dual Tasking**

Performing two activities simultaneously such as walking while texting or drinking coffee while driving is called dual tasking. McIsaac and colleagues have operationally
defined dual task as “the concurrent performance of two tasks that can be performed independently, measured separately, and have distinct goals” (McIsaac, Lamberg, & Muratori, 2015). When performing a single task, an individual must rely on executive function skills including the ability to attend to the environment, recognize appropriate task-related information, manipulate information in working memory, inhibit unnecessary information, organize and plan for a goal related action, and execute that plan while accounting for unexpected shifts along the way (Magill & Anderson, 2017). When performing dual task activities, the single task planning and execution factors listed above must now be carried out concurrently for both of the tasks. Thus, the attention normally given to the execution of each single task must now be shared between the two, making attentional resource management crucial. Typically, performing a dual task is more challenging than performing a single task and can lead to a performance decrement. A dual task can include a combination of two motor tasks (e.g., walking and texting) or a motor and a cognitive task (e.g. walking and talking). Attending to both tasks involves switching attention between the two in an organized or scheduled manner (Janssen, Brumby, & Garnett, 2012; McIsaac & Benjapalakorn, 2015; Plummer & Eskes, 2015). The scheduling of task switching, also called task interleaving, involves leaving one task (temporarily) to shift your attention to a second task, and then return to the original task (Janssen et al., 2019). This shift in attention between tasks can impact task performance. A change in performance outcome from single to dual task condition is called the “Dual Task Effect” (McIsaac, Fritz, Quinn, & Muratori, 2018; Plummer & Eskes, 2015). If attentional resources are insufficient to successfully execute both tasks when performed together, a performance decrement may occur in one or both of the tasks. This is known as the “Dual Task Cost.” Conversely, a “Dual Task Benefit” would occur if performing the two tasks together resulted in an improvement in either task. These relative dual task measures (dual task effect, cost, benefit) are used as proxies of processing load and attention allocation (McIsaac et al., 2015; Plummer & Eskes, 2015).
In order to best compare dual task and single task performance, it is important to measure the single and dual task outcomes for both tasks. Evaluation of the cost or benefit of each dual task is required for complete assessment of dual task function (McIsaac et al., 2015; Plummer & Eskes, 2015). The reciprocal performance effect that dual task components have on each other is critical to understanding the impact that specific impairments could have on overall task performance and prioritization.

**Task Prioritization**

As mentioned above, when two tasks are performed simultaneously, attentional resources must be allocated across dual task activities and performance of one activity may interfere with the other. In order to cope with the interference that one activity may have on another, individuals must prioritize their attentional resources for optimal results (Jansen, Van Egmond, & De Ridder, 2016; Kelly, Eusterbrock, & Shumway-Cook, 2013). Walking while texting under different conditions demonstrates a performer’s task prioritization. Texting may be prioritized over walking under conditions where there are no environmental impediments. However, if the ground was icy or laden with obstacles, an individual may choose to prioritize walking to avoid slipping or tripping and the text message may have more errors. Thus, task prioritization may be considered dynamic and flexible depending upon individual, task and environmental factors (Kelly et al., 2013).

Research designed to assess cognitive versus motor task prioritization has shown that healthy young adults will prioritize the cognitive task under simple walking conditions, but will prioritize the walking task under complex conditions (Kelly et al., 2013).

Research has demonstrated inherent prioritization preferences that differed based on the individual, task and environment but with practice, participants were able to shift away from their inherent priority when given explicit instructions to do so (Jansen et al., 2016). Shumway-Cook et al. proposed a hierarchy for prioritization of resource
allocation, suggesting posture would be a first priority in order to maintain safety. However, they found that aging adults do not consistently demonstrate this “posture-first” strategy (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Bloem at al. (2006) found that PwPD attempted to give equal priority to both cognitive and motor tasks but had difficulty assigning and shifting priority between the two tasks (Bloem, Grimbergen, van Dijk, & Munneke, 2006). During a simple walking task, PwPD can shift task priority almost as well as healthy controls (HC) when explicitly instructed to do so, but were unable to follow priority instructions during a complex walking task (Kelly & Shumway-Cook, 2014). This supports the idea that dual task effects are dependent on task constraints.

**Dual Task Ability in PwPD**

Overall, PwPD have difficulty with dual tasking, demonstrating increased cognitive- motor interference, and significant performance declines when walking under dual task conditions compared to their healthy peers (Kelly, Eusterbrock, & Shumway-Cook, 2012; Wild et al., 2013). Dual task interference has been shown to significantly impact gait velocity along with stride length, double limb support, step count and stride time variability (Kelly et al., 2012; Raffègeau et al., 2019; Wild et al., 2013). In PwPD, the negative changes in gait parameters seen dual tasking were significantly impacted by increased task complexity compared to healthy controls (Wild et al., 2013). There are multiple factors that may contribute to dual task difficulty in PwPD including: 1) reduced movement automaticity requiring an increased attentional demand for motor activities (Wu et al., 2015); 2) decreased executive function including task switching (Woodward et al., 2002) and response inhibition (Roussel et al., 2017); and 3) reduced control of attention (Dujardin et al., 2013).
The majority of dual task studies in PwPD have focused on upright activities such as standing or walking paired with a variety of secondary tasks (Foley, Kaschel, & Sala, 2013; McIsaac et al., 2018). Assessment of seated dual tasks, where balance requirements of walking are reduced, have not been well studied and there is a lack of information about dual task performance that involves the upper extremities (McIsaac et al., 2018). Findings from walking dual task studies may not generalize to seated tasks such as driving, where a different set of motor (steering and managing the acceleration/braking), and cognitive components (navigation and attending to environmental demands) are combined to form a complex dual task. The few seated dual task studies involving upper extremities in PwPD have examined various motor-motor and cognitive-motor tasks: 1) pegboard activity while squeezing a ball (Kalirathinam & Vaidya, 2014); 2) pegboard with a cognitive questionnaire (Kalirathinam & Vaidya, 2014); 3) pegboard activity with a serial 7 subtraction task (Proud & Morris, 2010); 4) donning a button-up shirt while reciting female first names (Teixeira & Alouche, 2007); and 5) a target tracking/force transduction task with backwards counting by 1s and 3s) (Pradhan et al., 2010). All these upper extremity studies found dual task performance significantly decreased for PwPD compared to healthy controls. One study evaluated a force tracking task performed with a secondary cognitive task under three levels of increasing cognitive task complexity and found decreased performance with increased cognitive task complexity (Pradhan et al., 2010). These studies only evaluated change in upper extremity motor task performance with the addition of the secondary task. They did not examine the change in the cognitive performance. Without this reciprocal comparison, our understanding of the dual task costs and prioritization patterns are incomplete. Although all studies reported show performance decrement with the addition of a dual task, generalizability is difficult due to the variation in motor-cognitive task combinations and their individual outcome measures.
Dual Task Assessment and the Clinch Token Transfer Test

A standardized approach to dual task assessment, using a reliable and valid outcome measure would allow for better understanding of dual task deficits and enable comparison between studies. There is currently no standardized, dual task assessment emphasizing use of the arms. Currently, the majority of dual task studies performed in PwPD have involved a postural component and none have focused on the use of upper extremities along with a cognitive task. The Timed Up & Go – Cognitive (TUG-COG) is the only standardized upright dual task assessment (Shumay-Cook, Brauer, & Woollacott, 2000) recommended for use in the PD population by the PD-EDGE Evidence Database to Guide Effectiveness (PD-Edge, 2014) of the American Physical Therapy Association. When completing the TUG, a participant begins seated in a chair. When told to “Go” the participant stands, walks 3 meters, turns around, walks back to the chair and sits down. They are told to do this as quickly as possible while maintaining safety. Time is the outcome for this assessment. The TUG-COG involves completion of the above task while performing serial subtraction by 3s. Although the TUG-COG is recommended for assessment in PwPD, there are no reports on reliability and validity in this population (PD-Edge, 2014). This test examines the cost of adding a cognitive task, (serial subtraction by 3s), on a motor outcome (time), but does not include the reciprocal assessment. Disregarding the impact of the motor performance on the cognitive task may lead to an incomplete conclusion about a dual task performance, concluding a pure motor deficit rather than an attentional allocation trade-off strategy between the two tasks (Plummer & Eskes, 2015). Without a standardized seated dual task assessment and only one upright assessment that has not addressed reciprocal cost, there has been no research comparing the motor-cognitive dual task cost pattern between seated and upright activities.
The newly designed Clinch Token Transfer Test (C3t) (Clinch, Busse, Lelos, & Rosser, 2018), evaluates the effect of both motor and cognitive dual task interference on performance of a seated, functional upper extremity task. The C3t combines a measure of bimanual dexterity with a dual task assessment. There are currently no standardized outcome measures for either bimanual dexterity or dual task ability that have been reported to be reliable or valid in PwPD. The 9-Hole Peg Test (9HPT) (Earhart et al., 2011), a commonly used dexterity measure, assesses only unimanual dexterity. Although the Dexterity Questionnaire-24 (DEXTQ-24) (Vanbellingen et al., 2016), includes bimanual activities, it is a subjective, self-report measure. The C3t includes manual dexterity activities, but has not been assessed for validity against other manual dexterity measure. Clinch and colleagues assessed the C3t for dual task validity against another assessment she created called the “Step and Stroop,” which she described as “two individual tests which were … combined to form a new dual task”. The research report indicated the “Stroop test” and “Step Test” had never been tested in combination in any population prior to development of the 2017 study (Clinch, 2017). Her validation analysis compared the C3t outcome measures (both total time and score) to measures of dual task performance rather than the more specific constructs of finger dexterity (Clinch, 2017).

The current study proposes to validate the C3t as a measure of manual dexterity in PwPD by comparing the baseline C3t condition to the 9HPT.

Although designed to address the degenerating basal ganglia circuitry in an HD population, the dexterity and executive function demands of the C3t will also challenge PwPD, who are also coping with basal ganglia degeneration. Currently available therapeutic outcome measures designed to individually assess motor and cognitive function are not sensitive enough to detect change in the very early stages of PD. Development of a standardized outcome assessment that combines cognitive and motor tasks in a dual task paradigm, may have the potential to detect deficits earlier in PD and to evaluate interventions that may address these combined impairments. Evaluating
patterns of motor and cognitive prioritization in the C3t and TUG dual tasks will help to understand if participants approach the execution of dual tasks with differing postural requirements in different ways. This is the first study to assess the C3t in a cohort of PwPD and the first to assess construct validity of the C3t (comparing to the 9 Hole Peg Test), as a measure of manual dexterity in HC and PwPD.

The aims of this study were:

**Aim 1**
To determine the test-retest reliability for the C3t in PwPD.

*Hypothesis:*
1.1 - The C3t baseline, complex and DT conditions will all demonstrate good test re-test reliability in PwPD.

**Aim 2**
To determine the construct validity of the C3t as a measure of manual dexterity.

*Hypothesis:*
2.1 - The C3t baseline condition will demonstrate construct validity compared to the 9HPT (the gold standard of assessment for manual dexterity in PD).

**Aim 3:**
To determine if the C3t conditions differ significantly: 1) Between healthy controls (HC) and PwPD; and 2) In relation to disease severity in mild PD and mod PD.

*Hypothesis:*
3.1 – HC will demonstrate better performance on all C3t task conditions than PwPD.
3.2 – Participants with mod PD will demonstrate poorer performance on all C3t task conditions than mild PD.
Aim 4:
To identify the motor and cognitive impairments that relate to C3t performance (score) on baseline, complex and dual task conditions in PwPD.

Hypothesis:
4.1- In PwPD, performance on all C3t conditions will be predicted by: MDS-UPDRS III score as an indicator of disease severity, Stroop and Trail-Making test scores as measures of executive function, and the Functional Dexterity Test as a measure of hand dexterity.

Aim 5:
To determine if task prioritization during the C3t (dual task condition) differs from the task prioritization during a dual task TUG with a cognitive interference measure for PwPD.

Hypothesis:
5.1 - PwPD will prioritize motor performance over cognitive performance on the dual task TUG and will prioritize cognitive performance over motor performance on the C3t dual task.

Aim 6:
To determine if the C3t movement components differ significantly: 1) Between healthy controls and PwPD and 2) In relation to disease severity in mild PD and mod PD for single compared to dual task conditions.

Hypothesis:
6.1 - Movement component will differ under the single and dual task conditions for PwPD. During the dual task conditions, longer movement times will be seen during the Coin Lift, Bilateral Transfer and Coin Release.
6.2 - During the dual task conditions, mod PD will demonstrate longer movement times during Coin Lift, Bilateral Transfer and Coin Release than mild PD.
Chapter II

METHODS

Study Design

A non-experimental, prospective study with both cross-sectional and longitudinal components was conducted to evaluate both the reliability and validity of the C3t in individuals with Parkinson’s disease as well as to determine performance predictors and prioritization choices during task execution.

Participants

Participants were recruited from local neurologists and through PD support groups and asked if they would like to participate in the study. Participants were divided into three groups: 1) **mild PD** (Hoehn & Yahr (H&Y)=I) (n=13); 2) **mod PD** (H&Y=II and III) (n=13); 3) **healthy controls** (HC) who were age, gender and education matched to the mild PD (n=13) (Hoehn & Yahr, 1967). The two PD participant groups were designed to differentiate between individuals with unilateral and bilateral symptoms. PD symptom sidedness and handedness were not controlled for nor analyzed. Participants were eligible for inclusion in the study if they met the following criteria: 1) age 40 or older; 2) H&Y stages I-III (Candan & Özcan, 2019). Criteria for exclusion included: 1) impaired cognition as indicated by the Montreal Cognitive Assessment (MoCA) score < 24/30, (Nasreddine et al., 2005); 2) a medical, neurologic, orthopedic or upper extremity pathology that would prevent the subject from performing any of the study
tasks; 3) major “on”/”off” motor fluctuations or moderate to severe tremor or dyskinesia (as noted by neurologist or self-report); or 4) colorblind (self-report).

The Teachers College and Marist College Institutional Review Boards approved this study. All participants signed informed consent including Health Insurance Portability and Accountability Act (HIPAA) consent.

**Data Collection**

In order to characterize the participants, the primary investigator, who is a certified rater for the Movement Disorders Society - United Parkinson’s Disease Rating Scale – Part III: Motor Examination (MDS-UPDRS III), collected cross-sectional demographic data. Participant demographics are summarized in Table 3. These data include scores from the MDS-UPDRS III (Goetz et al., 2008), H&Y assessment, and the MoCA. All PD participants were tested “on” Levodopa medication. They took their medication 1 to 1.5 hours prior to testing and all reported that with regard to their medication cycle, their physical functioning was optimal. During the first session, all participants were screened as above and completed the following assessments. **Measures of upper extremity motor function:** 1) Dexterity questionnaire (DEXTQ-24) (Vanbellingen et al., 2016); 2) Grip strength; 3) Pinch strength (Virgil Mathiowetz, Weber, Volland, & Kashman, 1984); 4) 9-hole peg test (9HPT) (Earhart et al., 2011); 5) Functional dexterity test (FDT) (Sartorio et al., 2013). **Measures of cognition:** 1) Alphabet baseline test; 2) Victoria Stroop test (Sisco, Slonena, Okun, Bowers, & Price, 2016); and 3) Trail Making – Part B test (Arbuthnott & Frank, 2000). **Dual task measures:** 1) C3t baseline (2 trials), value baselines, complex and dual-task conditions; 2) Timed Up and Go (TUG) test – baseline and dual task conditions; 3) 9-hole peg test under dual task conditions. The C3t, TUG and 9-hole peg tests were counterbalanced for order representation across participants. Participants were involved in two test sessions that occurred within 3 weeks. Figure 1
illustrates the study schema. Session 1 took approximately two hours to complete. During session 2, all PD participants repeated the C3t including C3t baseline, value baselines, alphabet baseline, complex and dual-task conditions. Session 2 was scheduled at the same time of day and at same point in each participant’s medication cycle as Session 1. Session 2 took approximately one-half hour. C3t performance during both sessions were recorded using a Sony Electronics, α-6300 mirrorless digital video camera (Tokyo, Japan) with a sampling rate of 120fps.

**Figure 1. Study Schema**

**Clinch Token Transfer Test (C3t)**

The C3t is a functional upper extremity dual task assessment originally designed to assess dual task ability in individuals with Huntington’s disease (Clinch, 2017; Clinch et al., 2018). This test involves the pickup and transfer of coins (different sizes and
values) from one hand to the other before being dropped into a coin bank under conditions of increasing complexity (Figure 2, Table 1).

Figure 2. Clinch Token Transfer Test (C3t).

Table 1. C3t Assessment Items and Procedure (modified from Clinch, 2017)

<table>
<thead>
<tr>
<th>Test Order</th>
<th>C3t Item</th>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alphabet Baseline</td>
<td>While sitting, the participant was asked to recite every other letter of the alphabet as quickly as possible. Starting letter was counterbalanced across participants.</td>
</tr>
<tr>
<td>2</td>
<td>Baseline Condition Practice Trial</td>
<td>The participant was asked to transfer tokens in order of size as quickly as possible. This first trial was a practice trial.</td>
</tr>
<tr>
<td>3</td>
<td>Baseline Condition Testing Trial</td>
<td>The participant was asked to transfer tokens in order of size as quickly as possible.</td>
</tr>
<tr>
<td>4</td>
<td>Value Baseline #1</td>
<td>While sitting, the participant was presented with 8 values (200,100,50,20,10,5,2,1) printed on a laminated card placed in from of them. The participant was asked to say aloud the highest value, working their way down to the lowest value. They were asked to do this as quickly as possible.</td>
</tr>
<tr>
<td>5</td>
<td>Value Baseline #2</td>
<td>While sitting, the participant was presented with 8 values (90,82,71,49,35,17,6,3) printed on a laminated card placed in from of them. The participant was asked to say aloud the highest value, working their way down to the lowest value. They were asked to do this as quickly as possible.</td>
</tr>
<tr>
<td>6</td>
<td>C3t Complex Trial</td>
<td>Same procedure as #3 but tokens presented had values printed on them (baseline values #1). The participant was asked to transfer the tokens in value order, starting from the highest value to the lowest as quickly as possible.</td>
</tr>
<tr>
<td>7</td>
<td>C3t Dual Task Trial</td>
<td>The participant was asked to recite every other letter of the alphabet, starting with a specified letter, as quickly as possible while performing the same procedure as #6. Tokens present had different values printed on them (baseline values #2).</td>
</tr>
</tbody>
</table>
The C3t includes assessment under three conditions of increasing complexity. The
C3t instruction manual can be found in Appendix G (Clinch, Busse, Lelos, & Rosser,
2017). In the **baseline condition (BL)**, considered a motor activity, the subject was
presented with 8 blank tokens arranged in order of decreasing size (Figure 3-A).
Instructions were as follows: “*Using your non-dominant hand I want you to pick up each
token individually, pass it to your dominant hand and put it in the container. I want you
to start with the largest token, so the one farthest from you and work your way down to
the smallest token which is closest to you. I want you to do this as quickly as possible and
I will stop the time after you have placed the last token into the container*” (Clinch et al.,
2017). In the **complex condition**, the motor complexity increased as the subject was
presented with 8 tokens arranged in order of size, with values printed on them
(Figure 3-B). Instructions were similar to the baseline condition except participants were
instructed to “*transfer the tokens in order of value, starting with the highest value and
ending with the lowest value.*” Finally, in the **dual task condition (DT)** the subject was
presented with 8 tokens arranged in order of size, with different values printed on them
(Figure 3-C). Instructions were similar to the complex condition except in the DT
condition, participants were instructed to “*transfer the tokens in order of value, starting
with the highest value and ending with the lowest value (motor portion of the DT).
While doing this, I want you to recite every other letter of the alphabet as quickly as you
can (cognitive portion of the DT).*” The cognitive portion of the DT differed from
Clinch (2017) as she had participants recite every letter of the alphabet. This modification
was made following initial pilot data collection as recitation of the entire alphabet was
not challenging due to familiarity with the alphabet task, as seen by participants asking if
they could “*sing the alphabet*” and entraining of the alphabet letters in a rhythm to the
coins.

Participants performed a practice trial of the baseline motor condition, followed by
a test trial. The practice trial allowed participants to become familiar with the task and
minimized any learning effects. After two trials of the baseline motor condition, participants were given two baseline cognitive tests. The baseline cognitive tests confirmed a participant’s ability to recite both the complex and dual task series of number values in descending order before initiation of the actual coin manipulation tasks. First, participants were shown a card with the complex coin values printed (Figure 3-B) and were given the following instructions, “Using the values printed on this card, I want you to say aloud the highest value and work your way in decreasing order of value to the lowest value. I want you to do this as quickly as you can and I will stop timing you once you have said the final value.” This was repeated with a complex value task where the card showed the values used in the dual task condition (Figure 3-C) (Clinch et al., 2017).

Figure 3. C3t Tokens for Each Condition
Participants were instructed, “If you drop a token and it falls or rolls outside of the test area please leave it and move onto the next token. If you drop the token and it falls on the surface in front of you, you can pick it up and continue.” The examiner recorded the time from the “go” signal until the final coin had dropped into the bank. The examiner also recorded number of errors made. Including the number of tokens dropped (drop error), number of tokens transported with the incorrect hand (transfer error) and the number of tokens transferred in the wrong size order or numerical order (rule error). A rule error involving incorrect coin size was possible during the baseline condition only. Rule errors involving incorrect numerical order were possible during complex and dual task conditions.

**C3t Scoring**

Multiple calculations were generated to produce an accuracy score (Figure 4) for each of the three conditions. The accuracy score contributed to the calculation of a total score (Figure 5) for each of the three conditions. The alphabet correct response rate (CRR) was calculated for both single (alphabet baseline) and dual task conditions (Figure 6). The single and dual task scores were used to calculate a dual task cost (DTC) for both motor and cognitive task components (Figures 7 and 8).

\[
\text{Task Accuracy (\%)} = \frac{16 - \text{combined # of transfer and rule errors}}{16} \times 100
\]

*Figure 4. C3t Accuracy Score Calculation. Number of rule and transfer errors made is subtracted from a total possible 16 errors (equivalent to 8 possible transfer errors and 8 possible rule errors), divided by 16 and multiply by 100.” A higher value indicates a better performance.*
Total Task Score

\[ \text{Total Task Score} = \frac{8 - \# \text{ tokens dropped out of reach}}{\text{Total time (s)}} \times \text{Task Accuracy} \]

*Figure 5.* C3t Total Score Calculation. Number of tokens dropped outside of the testing area is subtracted from a total of 8 possible coins, divided by the total time of the trial. This is then multiplied by the above generated accuracy score to determine the C3t total task score. A higher C3t total score indicates better performance and a lower score a decreased performance outcome. A higher rate indicates a better performance.

**Alphabet Correct Response Rate — CRR**

\[ \text{CRR} = \frac{\# \text{ correct letters recited}}{\text{Total time (s)}} \]

*Figure 6.* Alphabet Correct Response Rate

**Motor Dual-Task Cost/Benefit**

\[ \text{Motor Cost/Benefit} = \left( \frac{\text{Dual Task Score} - \text{Baseline Score}}{\text{Baseline Score}} \right) \times (+/-) 100 \]

*Figure 7.* Motor Dual Task Cost/Benefit Calculation. Placing the (+/-) before the 100 indicates that you need to consider the sign depending upon outcome measure used to keep a DTC consistently negative or a DTB consistently positive (e.g. CRR an increased value = better performance and time or duration a decreased value = better performance necessitating a negative multiplier for cost).

**Cognitive Dual-Task Cost/Benefit**

\[ \text{Cognitive Cost/Benefit} = \left( \frac{\text{Dual Task Alphabet CRR} - \text{Baseline Alphabet CRR}}{\text{Baseline Alphabet CRR}} \right) \times 100 \]

*Figure 8.* Cognitive Dual Task Cost/Benefit Calculation
Figure 9. Total Dual Task Effect Calculation

**C3t Movement Component Analysis**

The C3t task was digitally recorded for later movement analysis. Each C3t trial included 8 coin transfers. Each coin transfer of the C3t task was broken down into six movement components (Table 2 and Figure 10) as follows:

<table>
<thead>
<tr>
<th>Movement Component</th>
<th>Operational Definition</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Initial Reach</td>
<td>First movement of fingers to first finger contacting coin.</td>
<td>Movement initiation and ND hand transport</td>
</tr>
<tr>
<td>2 Coin Lift</td>
<td>Coin contact to coin completely lifted off support surface.</td>
<td>Object manipulation - ND hand</td>
</tr>
<tr>
<td>3 Non-Dominant Transport</td>
<td>Coin lift to first contact of D hand on the coin.</td>
<td>Task Switching</td>
</tr>
<tr>
<td>4 Bilateral Transfer</td>
<td>D hand contact to ND hand releasing contact with coin.</td>
<td>Bimanual coordination</td>
</tr>
<tr>
<td>5 Dominant Hand Transport</td>
<td>ND hand coin release to coin positioned over release slot.</td>
<td>In-hand manipulation</td>
</tr>
<tr>
<td>6 Coin Release</td>
<td>Coin positioned over release slot to coin no longer visible.</td>
<td>Object release - D hand</td>
</tr>
</tbody>
</table>

Table 2. Movement Component Analysis: Segment Descriptions and Rationale
We used Datavyu®, visualization and video-audio coding software (New York, New York), to analyze movement and spoken components of the coin transfer task at 60 fps. All coding was based on visual estimates. Analysis of kinematic data was based on visual inspection. The segments were time coded for all eight coins under baseline and dual task conditions for all participants so that duration of each segment and the relative portion of each segment as a percentage of the total movement time were obtained. During the dual-task condition, coding also identified the time point where recitation of each correct alphabet letter occurred. Using Datavyu’s spreadsheet “temporal alignment” feature, the recited alphabet letters were aligned to the movement components during which they were recited. Each video segment was analyzed frame by frame to determine the specific component onset and offset points for every participant. Each individual trial was reviewed three times. The first review was used to determine the total movement time for the trial; the second review was used to code the segment onset and offset positions; and the third review was used to identify the component during which each correct alphabet letter was stated.
Although the primary examiner coded all participants, a coding manual was developed to define the onset and offset rules for each movement component in order to maintain consistency (Appendix E). Certain exclusions were made. If a participant dropped a coin, the movement segments prior to the drop were included for analysis but the missing segments (post drop) could not be measured and were omitted from analysis. If a participant demonstrated a transfer error such that a single hand picked up, transported and released the coin, thus eliminating Bilateral Transfer and Dominant Transport segments (Table 2), that coin was not scored for inclusion in the analysis. Although participants demonstrated many variations of coin task execution, all six of the movement segments listed (Table 2) were identifiable using the coding manual’s rules.

**Motor Impairment Measures**

We assessed a range of motor impairment measures (patient reported and performance based) in order to evaluate their potential impact on C3t performance.

**Grip Strength**

Grip strength was assessed using a Dynatron Hydraulic Hand Dynamometer® (Salt Lake City, Utah). Participants performed three maximal efforts of grip strength, and the average of the three trials (measured in pounds) was recorded. Participants performed a whole hand “power” grasp and were asked to “grip the device as hard as you can”. This assessment was performed bilaterally with average values generated for the dominant and non-dominant hands.

Grip strength assessment via dynamometry has shown reliability and validity in an aging population as well as with individuals post stroke (Bellace, Healy, Besser, Byron, & Hohman, 2000; Bohannon & Schaubert, 2005; Boissy, 1999; Mathiowetz, Weber, Volland, & Kashman, 1984). Normal values of grip strength have been established as a
baseline for evaluation of hand impairment (Mathiowetz et al., 1985) and in a review of grip strength evidence, Bohannon (2019) concluded that there was adequate evidence to use grip force measures as a predictor of function in aging adults. Additionally, Martin and colleagues specifically found grip strength to be a predictor of hand dexterity in aging adults (Martin, Ramsay, Hughes, Peters, & Edwards, 2015), and Nowak and Hermsdorfer (2005) indicated that grip strength may be considered an important objective measure to include when evaluating manual performance deficits in individuals with neurologic movement disorders. Although these specific studies did not include PwPD, we know that when executing a power grasp, PwPD were found to demonstrate more movement arrests, a longer total movement time and higher peak forces than healthy controls (Pradhan et al. 2014). Thus, grip strength has the potential to impact object manipulation during C3t performance, as some participants may require more than a precision grip to complete the task.

**Pinch Strength**

Pinch strength was assessed using Dynatron Hydraulic Pinch Gauge® (Salt Lake City, Utah). Participants performed three maximal efforts of pinch strength and the average of the three trials (measured in pounds) was recorded. Participants performed a lateral pinch grasp and were asked to “grip the device as hard as you can.” This assessment was performed bilaterally with average values generated for the dominant and non-dominant hands.

Normative values of pinch strength in adults have been established (Mathiowetz et al., 1985), however reliability and validity data for pinch strength have not been published. Improvements in pinch force and the ability to maintain steadiness of pinch force was found to enable elderly participants to better control their precision grip with improved function on a fine manipulation task (Ranganathan, Siemionow, Sahgal, Liu, & Yue, 2001). However, when executing a precision grip (pinch), PwPD were found to
demonstrate delay between object contact with the first finger and object lift, with increasing delays noted with increased disease severity (Ingvarsson, Gordon, & Forssberg, 1997). When told to move as quickly as possible while releasing precision grip on an object, PwPD demonstrated a decreased force rate and a longer duration of force decrease compared to healthy controls (Gordon, 1998). Pradhan and colleagues (2010) examined precision grip in PwPD and found less accuracy in generating pinch forces when lifting a precision grip instrument, further, these deficits were exacerbated under dual task conditions and worsened with increased severity of motor symptoms. Thus, decreases in pinch strength have the potential to impact C3t performance during all movement components except for Initial Reach.

**Hand Dexterity (DEXTQ-24)**

The DEXTQ-24 is a self-report questionnaire examining functional hand dexterity (Vanbellingen et al., 2016). Participants rated their perceived level of difficulty performing a series of 24 common functional activities on a four-level ordinal scale. On this scale 1 = no difficulty and 4 = “needs assistance.” The highest score possible, if needing assistance with all tasks is 96. A lower score indicates a higher level of function. The tool does not specify if participants are to respond considering performance with their dominant or non-dominant hands. This tool was found to be a reliable and valid way to measure hand dexterity in PwPD (Vanbellingen et al., 2016). This measure of perceived hand dexterity was used to determine the relationship of hand dexterity on C3t performance.

**9-Hole Peg Test**

The 9HPT test is widely considered a gold standard measure for manual dexterity in PwPD (Earhart et al., 2011; Wang, Bohannon, Kapellusch, Garg, & Gershon, 2015). Participants took 9 pegs individually from a container and placed them into 9 individual holes on a board as quickly as possible. Participants then individually removed the pegs
and returned them to the original container as quickly as possible. Performance was assessed using both the dominant and non-dominant hand. This test was repeated twice with each hand and best score was taken. Due to the size of the pegs, participants typically employ pinch grasp for completion of this assessment. The 9HPT has high test-retest reliability in PwPD (Earhart et al., 2011). The score for this outcome measure was total time (seconds) to complete the task. The 9HPT was used to determine the potential effects of dexterity on the C3t and to use as a gold standard when establishing criterion validity of the C3t in PwPD.

**Functional Dexterity Test (FDT)**

The FDT is a test measuring manual/finger dexterity skills (Aaron & Stegink Jansen, 2003). This test required a 3-jaw chuck grasp for peg manipulation due to peg size and task requirements. Participants used one hand to lift a peg from a hole in a wooden box, rotate the peg 180 degrees and place it back into the original hole. Sixteen pegs were flipped as quickly as possible and the total task time is recorded. Participants performed this assessment with both their dominant and non-dominant hands. Participants were not allowed to supinate the hand being tested or rest the hand on the wooden box and participants received a time penalty for errors made: penalty for touching the board (+5 sec); penalty for supinating the hand (+5 sec); penalty for dropping a peg (+10 sec). The time penalties were added to the total task time for a final time score. Reliability was originally assessed on adults with hand injuries and good intra-rater reliability was found for both the injured and non-injured hands (Aaron & Stegink, 2003). Validity studies indicated a correlation between the FDT and only functional activities requiring a 3-jaw chuck manipulation indicating further validity studies were required (Aaron & Stegink, 2003). Later FDT reliability studies demonstrated inter and intra-rater reliability in healthy adult population (Sartorio et al., 2013). The FDT has also been reported to be a reliable and valid instrument for
measuring manual dexterity in children (Tissue et al., 2017). Although not validated in PwPD, the FDT may be a better predictor of dexterity on the C3t than the 9-hole peg test due to the specific type of grasp (3-jaw chuck) required to successfully accomplish both the FDT and C3t tasks.

**Cognitive Impairment Measures**

Three measures of cognition were included, in addition to the MoCA, which was used as a screening tool. These measures were chosen due to their sensitivity to cognitive impairments in individuals with Parkinson’s disease.

**Alphabet Baseline**

Participants were assessed with an alphabet baseline and were given the following instructions, “Starting with A, I would like you to recite every other letter of the alphabet, pronouncing each letter, as quickly as possible. I will stop timing you once you have said your final letter.” Starting letters of A, B and C were counterbalanced for the alphabet baseline. The alphabet baseline (CRR) was used to compare to dual-task cognitive performance under single and dual task conditions in order to identify cognitive cost/benefit measures.

**Victoria Stroop Test**

The Stroop test is a cognitive assessment that measures the ability to inhibit a habitual response and generate one that is less familiar (Stroop, 1992). The Victoria Stroop includes 24 items under three conditions: 1) naming the color of dots; 2) naming the color ink of neutral words (i.e., the word “when” printed in color red); and 3) naming the color ink of color words (i.e., “blue” printed in the color red). Participants needed to inhibit the response of the printed word “blue” in order to recite the ink color of the printed word—“red.” Outcome score for this assessment was total time (sec) for each
section. An index of interference was calculated by dividing condition 3 by condition 1 to determine the interference effects of this task. Victoria Stroop test performance was used to determine if difficulty inhibiting habitual responses has an impact on C3t- dual-task performance (e.g., executing coins in order of value over size, and using non-dominant hand over dominant hand).

**Trail Making B Test**

The Trail Making B test (TMT) is a cognitive assessment of attention, working memory and task switching ability (Arbuthnott & Frank, 2000). Participants were required to use a pen or pencil to connect circles on a sheet of paper in sequential order, alternating between numbers and letters (e.g. A – 1 – B – 2, etc.). Time (sec) to connect 25 circles was measured. A comprehensive construct validity review of TMT indicated that this test reflects working memory and task switching abilities. Normative data is available for TMT, stratified by age and education level (Tombaugh, 2004). The ability to switch between tasks can be impaired in PwPD (Cameron, Watanabe, Pari, & Munoz, 2010). The TMT is often used as a baseline measure in studies examining executive dysfunction in PD (Kokubo et al., 2018; Müller et al., 2017; Rektorová et al., 2005). Reliability and validity of the TMT in PwPD has been demonstrated (Hurtado-Pomares et al., 2018). The TMT was used to determine if difficulty switching between tasks has an impact on C3t- dual-task performance.

**Dual Task Motor Measures**

The C3t allows for dual task assessment while a participant is seated. The seated position lessens postural task demands compared walking or standing. In order to compare a participant’s dual task prioritization, comparisons will be made to the Timed Up & Go test (TUG) performed under dual task conditions.
Timed Up & Go

The TUG, modified from “Get Up and Go” measure designed by Mathius, Nayak and Isaacs (1986), has become the gold standard for mobility assessment and fall risk in the aging population, has been used commonly in PwPD (Da Silva, Faria, Santos, & Swarowsky, 2017; Mathias, Nayak, & Isaacs, 1986; Podsiadlo & Richardson, 1991). A dual-task version of the TUG, involving a cognitive secondary task (serial 3 subtraction) (TUG-COG) has been used extensively as an assessment for upright, dual task function in PwPD (Campbell, Rowse, Ciol, & Shumway-Cook, 2003; Christofoletti, Andrade, Beinotti, & Borges, 2014; Maranhão-Filho, Maranhão, Lima, & Silva, 2011; Vance, Healy, Galvin, & French, 2014).

The TUG test requires participants to stand up from chair, walk three meters, turn around, walk back to the chair, and sit down as quickly as possible (Podsiadlo & Richardson, 1991). Participants are allowed to use the armrests for standing assist as needed. In the dual task TUG condition, participants performed the task as described above in conjunction with the addition of a secondary cognitive task (Campbell et al., 2003). For the purpose of this study, the secondary task involved stating every other letter of the alphabet as quickly as possible. The TUG was completed twice, once under single task and once under dual task conditions. No practice was provided.

Comparisons were made between the TUG with a cognitive dual-task component and the C3t dual task condition to identify if motor and/or cognitive task prioritization differs between seated and standing tasks.

9-Hole Peg Test-Dual Task

The 9HPT, described above as the gold standard for dexterity assessment, has not been evaluated for use as a dual task. Participants completed one additional trial of the 9HPT under dual task conditions, using their dominant hand. Participants were instructed to, “perform the 9HPT as they had been previously instructed.” In addition, they were instructed to “recite every other of the alphabet while placing the pegs into the container"
and to continue reciting the letters while taking the pegs out of the container.” Pilot testing revealed that if the instructions were not delivered in this way, participants stopped their letter recitation when the last peg was placed into the hole and did not continue the recitation while the pegs were removed. This dual-task assessment was included to determine if the 9HPT might also function as a dexterity dual task assessment. This information will be used for subsequent secondary analyses and will not be reported here.

Data Analysis

All analyses were performed with SPSS version 25 (IBM Corporation, Armonk, NY). Data were checked for normalcy (skewedness <-1 or > +1 was considered a non-normal distribution). The 9-hole peg test for the dominant hand and the Trail-Making B both demonstrated a non-normal distribution. The 9HPT was only used for analyses in Aim #2 where a Spearman correlation was substituted for a Pearson for the skewed distribution of the dominant hand. The Trail-Making B was entered into a regression as a possible predictor for C3t performance. Specific analyses are detailed under each aim. Alpha was set at ≤ 0.05. Primary data analysis specifically addressed the six main aims of this study. Data were considered outliers and excluded from analysis if they were greater than 3 SD above or below the mean.

Aim 1

To determine the test-retest reliability for the C3t in PwPD.

Data analysis. Test-retest reliability was evaluated using intraclass correlation coefficients (ICCs). Levels of reliability: values >0.75 indicate good reliability; values from 0.50 to 0.75 indicate moderate reliability; and values below 0.50 indicate poor reliability (Portney & Watkins, 2015).
When evaluating DT ability, it is good practice to consider both the motor and the cognitive performance measures (McIsaac et al., 2015). Reliability of the DT condition will consider both the reliability of the C3t DT score (motor performance) and the reliability of the Alphabet correct response rate - CRR (cognitive performance).

Aim 2
To determine the construct validity of the C3t as a measure of manual dexterity.

Data analysis. Construct validity was evaluated by comparing baseline C3t (single task) to the 9-hole peg test using a Pearson product-moment correlation for the non-dominant hand and a Spearman correlation for the dominant hand (skewed distribution).

Aim 3
To determine if the C3t conditions differ significantly: 1) between healthy controls and PwPD; and 2) in relation to disease severity in mild PD and mod PD.

Data analysis. We compared C3t performance between HC and all PwPD on baseline, complex and dual task conditions using a repeated measures ANOVA (2 groups x 3 conditions). Post hoc analysis for the ANOVA was conducted using the Scheffé test. Additional post hoc analyses conducted using one-way ANOVAs: Individual Condition Score x 2 (groups).

Additional analyses compared between HC, mild and mod PD groups conditions using a repeated measures ANOVA (3 groups x 3 conditions). Post hoc analysis for the ANOVA was conducted using the Scheffé test. Additional post hoc analyses conducted using one-way ANOVAs: Individual Condition Score x 3 (groups).

C3t transfer, rule and dropped errors made during task analysis were tabulated and observed for patterns.
Aim 4

To identify the motor and cognitive impairments that relate to C3t performance (score) on baseline, complex and dual task conditions in PwPD.

Data analysis. Individual linear stepwise regressions were used to determine which motor and cognitive impairments related to C3t baseline, complex and dual task performance. A correlation matrix was created entering all variables predicated to have an impact on the C3t outcome. The correlation matrix included: age, education years, MDS-UPDRS III Motor Score, MoCA score, Stroop test, Trail Making B test, grip strength right and left, pinch strength right and left, 9-hole peg test right and left, and FDT dominant and non-dominant hand final score. Variables demonstrating a significant correlation to baseline or complex condition were entered into that specific regression analysis. Any variables correlating to baseline, complex, or dual task condition scores were entered into the dual task regression model. Adjusted R Square values were reported because it is a more stringent measure of variance explained as it adjusts for adding additional regression measures.

Aim 5

To determine if task prioritization during the C3t (dual-task condition) differs from the task prioritization during a dual task TUG with a cognitive interference measure for PwPD.

Data analysis. The motor and cognitive dual task costs were plotted for each participant for the TUG and C3t tasks (illustration of plot see Figure 11). To quantify the total dual task cost, the motor and cognitive dual task costs were summed for each task (TUG and C3t separately) and the three groups (healthy control, mild PD and moderate PD) were compared using a two-way repeated measures ANOVA. No post hoc analyses were performed as the ANOVA showed no significant differences between the groups for either condition.
Aim 6

To determine if the C3t movement components differ significantly: 1) Between healthy controls and PwPD; and 2) in relation to disease severity in mild PD and mod PD for single compared to dual task conditions.

Data analysis. We compared C3t single and dual task movement components across healthy control, mild and moderate PD groups using a repeated measures ANOVA (3 groups x 2 conditions). Post hoc analysis for the ANOVA was conducted using the Scheffé test. Additional post hoc analyses conducted using one-way ANOVAs: Individual components x 3 (groups).
Chapter III

RESULTS

Demographic and baseline data for healthy controls (n=13), participants with mild PD (n=13) and moderate PD (n=13) are shown in Table 3. One individual with mild PD and one with moderate PD missed session 2 and were excluded from reliability testing analysis. Sessions were missed due to scheduling conflicts and transportation issues. Following an outlier analysis, one participant’s C3t complex score was excluded from analyses for aims 1-4 due to their C3t performance scores were greater than 3 SD above the mean (mod PD: n=1). Despite being in the mod PD group, this participant’s C3t performance was very fast and error-free, generating unusually high outcome scores. One participant was excluded as an outlier during movement component analysis (mod PD: n=1). This participant had great difficulty with manual dexterity, used an atypical grasp and release pattern and moved very slowly, thus their movement times were greater than 3 SD above the mean.

Baseline Demographics

The two PD groups were categorized according to their unilateral (mild PD) or bilateral (mod PD) symptom presentation as per their H&Y classification. Despite their difference in symptom presentation, the two PD groups had similar age range, gender breakdown, levels of cognition and education. As anticipated mod PD participants presented with a larger MDS-UPDRS III score than the mild PD group, indicating
Table 3. Participant Demographics and Performance on Disease-specific and Functional Measures

<table>
<thead>
<tr>
<th></th>
<th>Healthy Controls n=13</th>
<th>mild PD n=13</th>
<th>moderate PD n=13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>67.5 (8.2)</td>
<td>66.9 (8.7)</td>
<td>68.6 (8.4)</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>7:6</td>
<td>7:6</td>
<td>7:6</td>
</tr>
<tr>
<td>Education (yrs)</td>
<td>16.9 (1.8)</td>
<td>16.9 (2.3)</td>
<td>16.7 (3.2)</td>
</tr>
<tr>
<td>Hand Dominance (R:L)</td>
<td>13.0</td>
<td>12:1</td>
<td>11:2</td>
</tr>
<tr>
<td>Side of PD Onset (R:L)</td>
<td>N/A</td>
<td>4:9</td>
<td>8:4:1 (unknown)</td>
</tr>
<tr>
<td>Hoehn &amp; Yahr Scale</td>
<td>N/A</td>
<td>I=13</td>
<td>II = 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>III = 10</td>
</tr>
<tr>
<td>MDS-UPDRS III</td>
<td>N/A</td>
<td>11.5 (4.7)</td>
<td>* 33.5 (10.7)</td>
</tr>
<tr>
<td>MoCA</td>
<td>28.1 (1.9)</td>
<td>27.9 (1.2)</td>
<td>26.4 (1.7)</td>
</tr>
<tr>
<td>DextQ-24</td>
<td>24.5 (1.4)</td>
<td>28.9 (4.9)</td>
<td>* 37.9 (11.7)</td>
</tr>
<tr>
<td>Grip Strength R/L (lbs)</td>
<td>66.2 (22.1)/64.0 (23.6)</td>
<td>65.3 (18.4)/57.2 (24.9)</td>
<td>60.3 (25.8)/57.2 (24.9)</td>
</tr>
<tr>
<td></td>
<td>15.7 (6.7)/14.8 (7.3)</td>
<td>15.5 (3.3)/14.5 (4.7)</td>
<td>12.2 (6.8)/11.7 (4.9)</td>
</tr>
<tr>
<td></td>
<td>20.8 (3.4)/22.7 (4.5)</td>
<td>t/</td>
<td>23.9 (4.7)/26.1 (4.1)</td>
</tr>
<tr>
<td>9HPT (D/ND) (sec)</td>
<td>34.9 (24.5)/33.4 (24.9)</td>
<td>t/</td>
<td>31.1 (9.4)/44.0 (29.0)</td>
</tr>
<tr>
<td>Stroop</td>
<td>15.0 (5.0)</td>
<td>14.4 (7.2)</td>
<td>17.7 (5.9)</td>
</tr>
<tr>
<td>TMT (sec)</td>
<td>71.1 (19.5)</td>
<td>73.9 (34.3)</td>
<td>* 118.8 (64.9)</td>
</tr>
</tbody>
</table>

All values are shown mean(SD). Movement Disorders Society - United Parkinson's Disease Rating Scale - Motor Examination (MDS-UPDRS III); Montreal Cognitive Assessment (MoCA); Dexterity Questionnaire 24 (DextQ-24); 9-Hole Peg Test (9HPT); Functional Dexterity Test (FDT); Stroop Interference Effect (Stroop); Trail Making Test B (TMT). No significant differences noted between HC and mild PD. t indicated significant differences between HC and moderate PD (p<0.05). * indicates significant differences between mild and moderate PD groups (p<0.05).
increased severity of their motor symptoms and confirming that the two proposed groups were indeed different. The moderate PD group had greater self-reported hand function limitation on the DextQ-24 than the mild PD group. This perceived group difference was also demonstrated in the 9HPT (dominant hand) performance as the mod PD group showed greater manual dexterity impairment than the mild PD group.

**Test-Retest Reliability**

ICC values for baseline, complex and dual task C3t scores comparing session 1 and session 2 were calculated for 24 PwPD (mild PD n=12, moderate PD n=11). Three participants were excluded from this analysis. Two because they did not complete the follow-up testing session #2 and one because their C3t complex performance score was greater than 3SD above the mean (n=1 in the mild PD group and n=2 in the moderate PD group). The ICC value for the baseline condition score was 0.93 (95% CI 0.84 – 0.97) and 0.84 for the complex condition (95% CI 0.66 – 0.93) indicating good test-retest reliability. The ICC value for the C3t dual task condition score was 0.33 (95% CI -0.96 – 0.65), indicating poor test-retest reliability for the motor portion of the dual task activity. The ICC value for the test-retest reliability for the DT alphabet correct response rate (CRR) was 0.517 (95%CI 0.152 – 0.758) indicating moderate test retest reliability for the cognitive portion of the dual task activity.

To investigate whether the poor test retest reliability in the C3t dual task motor portion was a function of the scoring criteria (shown in Figure 5), this aspect of reliability was assessed using two alternate measures. Alternative measures included: 1) time to complete the dual task without consideration of errors (*total time*) and 2) modified total time, created by adding a 5 second penalty for every dropped coin, transfer error, or rule error (*modified time*). The ICC value using *total time* as a measure was 0.97 (95% CI 0.92 - 0.99) for the baseline condition (indicating good test-retest reliability), 0.81 (95%
CI 0.60 - 0.91) for the complex condition (indicating good test-retest reliability), and 0.64 (95% CI 0.32 – 0.83) for the dual task condition (indicating moderate test-retest reliability). The ICC value using modified time as a measure was 0.148 (95% CI -0.255 - 0.507) for baseline condition, 0.360 (95% CI 0.54 - 0.604) for the complex condition, and 0.452 (95% CI 0.163 – 0.670) for the dual task condition (indicating overall poor test-retest reliability). While use of total time proved to be a more reliable measure for baseline, complex and dual task conditions compared to the total score, the total score was used for all remaining analyses. Importantly, the total score takes into consideration participant errors, which is an important component of understanding dual task performance.

**C3t Construct Validity**

Construct validity of the C3t baseline condition, as a measure of manual dexterity, was evaluated by comparing session 1 C3t baseline performance to the 9HPT performed with the dominant and non-dominant hands. The Spearman r for the 9HPT was -0.84; p<0.001 for the dominant hand and the Pearson r was -0.85; p<0.001 for the non-dominant hand indicating a strong correlation between the two measures. Figures 12 and 13 shows scatter plots of the relationship between A) 9HPT - dominant hand and the C3t baseline performance and B) 9HPT - non-dominant hand and the C3t baseline performance.
**Figure 12.** Scatter Plot of the Relationship between 9HPT-dominant Hand and the C3t Baseline Performance ($r=-0.84$, $p<0.001$).

**Figure 13.** Scatter Plot of Relationship between 9HPT-non-dominant Hand and the C3t Baseline Performance ($r=-0.85$, $p<0.001$).
C3t Performance in People with Parkinson’s Disease and Healthy Controls

Mild and mod PD groups were combined and C3t performance scores were compared to that of HC (Figure 14). C3t scores for all participants declined as the testing conditions became more complex. There was a significant difference between HC and PD groups on baseline and dual task conditions. There were significant main effects of condition ($F(2,35)=115.25; p<0.001, \mu^2=0.87$) and of group ($F(1,36)= 15.95, p <.001, \mu^2=0.31$). There was a significant condition by group interaction ($F(2,35)=6.20; p=0.01$).

![C3t Scores Healthy Controls vs PwPD](image_url)

**Figure 14.** C3t Scores for Baseline, Complex and Dual Task Condition for HC vs All PwPD Combined. Significant differences between the two groups across all C3t conditions. On this “notBox Plot” (R. Campbell, 2017), the black center line indicates the group mean, the light areas of each bar indicate the standard deviation and the dark area of each bar indicates the 95% confidence interval. Gray circles represent all individual participant scores. The black circle-to-circle lines indicates the significance pairwise comparisons between HC and PwPD. The gray circle-to-circle lines indicate the non-significant pairwise comparisons between HC and mild PD and explaining the condition x group interaction.
μ²=0.26) indicating group differences were not similar for all three conditions and requiring post hoc analysis. Post hoc revealed that HC demonstrated better performance than PwPD on baseline (F(1,36) = 17.65; p<.001), complex (F(1,36) = 8.69; p<.01), and dual task (F(1,36) = 10.15; p<.01) conditions.

To further evaluate the differences between the three groups, a two-way analysis of variance was conducted to evaluate the effects of group and task condition on C3T performance (Figure 15). Groups included three levels (HC, mild PD and mod PD) and task condition included three levels (baseline, complex and dual tasks). C3t scores for all three groups declined as the testing conditions became more complex. There was a significant difference between HC and Mod PD for all three conditions. These findings are supported by a significant main effect of condition (F(2,34) = 135.06; p<0.001, μ²=0.89) and of group (F(2,35) = 16.42; p<.001, μ²=0.48). There was a significant condition x group interaction (F(4,68) = 8.33; p<.001, μ²=0.33) requiring further post hoc analyses. Post-hoc analysis revealed HCs performed significantly better than the mod PD group on baseline (F(2,35) = 17.52; p<.001), complex (F(2,35) = 15.88; p<0.001) and dual task (F(2,35) = 5.29; p<0.05) conditions.

Mild PD performed better than mod PD on baseline (F(2,35) = 17.52; p<0.01) and complex (F(2,35) = 15.88; p<0.01) but not on the dual task (F(2,35) = 5.29; p=0.76) condition. However, there were no significant differences between healthy control and mild PD group for baseline (p=0.058), complex (p=0.60) or dual task (p=0.07) conditions.
Figure 15. C3t Scores for Baseline, Complex and Dual Task Conditions for the Three Participant Groups. Significant differences found between HC and mod PD across all conditions, mild and mod PD on baseline and complex but not dual task conditions. No differences found between HC and mild PD. On this “notBox Plot” (Campbell, 2017), the black center line indicates the group mean, the light areas of each bar indicate the standard deviation and the dark area of each bar indicates the 95% confidence interval. Gray circles represent all individual participant scores. The black circle-to-circle lines indicate the significance of the pairwise comparisons between groups. The light blue circle-to-circle lines indicates the significance of the pairwise comparisons between HC and mild PD. The light red circle-to-circle lines indicates the significance of the pairwise comparisons between mild and mod PD groups.

Errors made by participants during performance of the C3t task conditions were analyzed and tabulated (see Table 4). One error occurred across groups during the baseline condition, 3 errors during the complex condition compared to 48 total errors made across groups during the dual task condition indicating increased errors were made as the task condition became more complex. Regarding the transfer errors, 4 participants used their non-dominant hand when making transfer errors (HC n=2, mild PD n=1, mod
PD n=1); 3 participants used their dominant hand when making transfer errors (HC n=0, mild PD n=2, mod PD n=1); and 1 participant demonstrated an error but the hand used was unknown due to a digital recording error. Thus, no consistent pattern of error occurred across participants or participant groups. Additionally, of the 10 participants demonstrating C3t errors, only 2 demonstrated both a transfer (motor) and rule (cognitive) errors during the same trial (HC n=1, mild PD n=0, mod PD n=1), where everyone else produced either transfer or rule errors, suggesting a primary area of focus during task execution.

Table 4. Participant Errors Made during Performance of C3t Task Conditions

<table>
<thead>
<tr>
<th></th>
<th>Transfer</th>
<th>Rule</th>
<th>Dropped</th>
<th>Transfer</th>
<th>Rule</th>
<th>Dropped</th>
<th>Transfer</th>
<th>Rule</th>
<th>Dropped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1 (n=1)</td>
<td>0</td>
<td>0</td>
<td>1 (n=1)</td>
<td>5</td>
<td>(n=4)</td>
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<tr>
<td>Complex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Dual Task</td>
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<td></td>
</tr>
<tr>
<td>HC</td>
<td></td>
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<tr>
<td>Mild PD</td>
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<td></td>
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<tr>
<td>Mod PD</td>
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</tbody>
</table>

Errors are presented as total number of errors with the (n = ) indicating the total number of participants responsible for producing the total number of errors. A transfer error indicates a coin transferred in the incorrect hand. A rule error indicated coins transferred in an incorrect size (baseline) or value (complex or dual task) order. A coin is considered “dropped” if it fell outside the testing area and was not retrieved.

**Relationship of Motor and Cognitive Impairments to C3t Performance**

Linear stepwise regressions were conducted to determine which cognitive and motor impairments related to performance on each of the C3t task conditions. Variables entered into the regression models based on significant correlation included:

- MDS-UPDRS III (ICC= -0.67, p< 0.001);
- Stroop Interference Effect (ICC= -0.37, p< 0.05);
- 9HPT dominant (ICC= -0.79, p< 0.001) and non-dominant hand (ICC= -0.84, p< 0.001), the Functional Dexterity Test – dominant hand (ICC= -0.40, p< 0.05) and the DextQ-24 (ICC= -0.36, p<0.05).

The 9HPT performed with the dominant and non-dominant hand were the two items found to predict C3t baseline performance in PwPD. The final regression model
included non-dominant hand 9HPT (R2=0.676) + the dominant hand 9HPT (R2=0.063) accounting for 73.9% of the variance (F(2, 23) = 36.48, p<0.001, R2 = 0.739).

The 9HPT performed with the dominant and non-dominant hand along with the Stoop Test were the three items found to predict C3t complex performance in PwPD. The final regression model included dominant hand 9HPT (R2=0.525) + non-dominant hand 9HPT (R2=0.073) + Stroop (R2=0.054) accounting for 65.2% of the variance (F(3, 21) = 15.97, p<0.001, R2 = 0.652).

The Stroop Interference Effect was the only item found to predict C3t dual task performance in PwPD. The final regression model included Stroop (R2=0.232) accounting for 23.3% of the variance (F(1, 23) = 8.24, p<0.01, R2 = 0.232).

**Task Prioritization During C3t and TUG Dual Task Performance**

The motor and cognitive dual task costs for the C3t and TUG tasks are shown in Figures 16 and 18. Figure 16 shows that during the C3t, all but one participant (mod PD) demonstrated mutual interference (Figure 16, quadrant IV), indicating decline in both motor and cognitive performance. Even within a single quadrant, it is possible to examine prioritization. Equal priority, even for mutual interference is indicated if data points fall along or close to the diagonal line in the 4th quadrant (Figure 17). Data points falling in the upper left portion of the 4th quadrant indicate a motor priority and those in the lower right portion of the 4th quadrant indicate a cognitive priority (McIsaac et al., 2015). With the mutual interference quadrant, 58% (n=22) of all study participants demonstrated a motor priority, 13% (n=5) an equal priority and 29% (n=11) a cognitive priority. Within the mod PD group, 58% (n=7) demonstrated motor priority, 25% (n=3) demonstrated equal priority and 17% (n=2) demonstrated a cognitive priority. Within the mild PD group, 46% (n=6) demonstrated motor priority, 8% (n=1) demonstrated equal priority and 46% (n=6) demonstrated a cognitive priority. Within the HC group, 69% (n=9)
demonstrated motor priority, 8% (n=1) demonstrated equal priority and 23% (n=3) demonstrated a cognitive priority.

Figure 16. C3t Prioritization Plot Demonstrating Mutual Interference for All but One Participant. Quadrant I indicates a motor priority trade-off (improvement of the motor task with decline in performance of the cognitive task). Quadrant II indicates a mutual facilitation, performance improvement in both tasks. Quadrant III indicates a cognitive priority trade-off (improvement in the cognitive task with decline in performance of the motor task). Quadrant IV indicates mutual interference, decline in both motor and cognitive single task performance due to simultaneous task performance.
Figure 17. Mutual Interference Prioritization Schema (McIsaac et al., 2015). This is a reproduction of Figure 13, quadrant IV, Dual task interference for the C3t Task. Quadrant IV is bisected by a dashed line that indicates where data points would fall if participants gave equal task priority to motor and cognitive tasks. Data points that fall above the dashed line indicate a cognitive priority. Data points that fall below the dashed line indicate a motor priority.

Prioritization during the dual task TUG can be seen in Figure 18, where participants demonstrated a varied cost prioritization profile. Fifty-four percent of participants demonstrated a mutual interference (Figure 18, quadrant IV) (HC n=13, mild PD n=13, mod PD n=13), indicating decline in both motor and cognitive performance. Forty-one percent demonstrated a motor or cognitive priority trade off indicating that they prioritized one task at the expense of the other. Of this 41%, 18% demonstrated a motor task prioritization (Figure 18, quadrant I) (HC n=3, mild PD n=2, mod PD n=2) and 23% demonstrated a cognitive task prioritization (Figure 18, quadrant III) (HC n=4, mild PD n=2, mod PD n=3). Five percent of participants demonstrated mutual facilitation (Figure 18, quadrant II) (HC n=2) indicating that performing the two tasks together allowed for improved performance in both cognitive and motor tasks. With the exception of quadrant II (mutual facilitation), the other three quadrants include data points from all conditions.
participant groups, indicating the prioritization strategy chosen for the dual task TUG performance is not related to disease severity.

Figure 18. TUG Prioritization Plot Showing a Varied Cost Prioritization Profile across All Participants. Quadrant I indicates a motor priority trade-off (improvement of the motor task with decline in performance of the cognitive task). Quadrant II indicates a mutual facilitation, performance improvement in both tasks. Quadrant III indicates a cognitive priority trade-off (improvement in the cognitive task with decline in performance of the motor task). Quadrant IV indicates mutual interference, decline in both motor and cognitive single task performance due to simultaneous task performance.

A total dual task effect value was calculated by adding the motor DTC or DTB with the cognitive DTC or DTB for each participant. The total dual task effect value represented the combined motor and cognitive effects rather than an either/or choice (see Figure 9 for equation). There were no significant differences in the mean (SD) total effect across groups for the C3t (HC -110.2 (20.7); mild PD -111.8 (19.0), moderate PD -106 (19.8; F(2,36)=0.292; p=0.748) or for the TUG (HC -24.0 (33.8), mild PD -38.6 (35.8), moderate PD -38.2 (60.0); F(2,36)=0.446; p=0.643). When comparing the total
effect of the C3t and the TUG across groups, there was a greater total cost of the C3t (t= -11.04; p<0.001, Figure 19), indicating that the C3t was a more difficult dual task for all participants.

![Total Dual Task Effect: Comparison C3t vs TUG](image)

**Figure 19.** Dual Task Total Effect Shown across All Participants for the C3t and DT TUG Tasks. C3t has a greater overall effect with little variability where the TUG has a small overall effect with a large variability. The mean (SD) total effect values, indicating the relative change from baseline condition to dual task are shown in the embedded table. The dotted line indicates no effect, above the line indicates a benefit and below the line indicates a cost. On this “notBox Plot” (R. Campbell, 2017), the black line indicates the group mean, the light areas of each bar indicate the standard deviation and the dark area of each bar indicates the 95% confidence interval. Colored circles represent all individual participant scores with participant groups represented according to the legend.

**Movement Component Analysis**

Each coin transfer was divided into six movement segments to analyze the relative movement components and their contribution to total task performance (see Table 2 and Figure 10 for component descriptions). The components were analyzed according to the
time taken to complete each component (movement time, MT) and as a percentage of
time spent in each movement component as a function of the total time of each coin
transfer (%MT). MT for each of the six movement components for the baseline and dual
tasks condition for each participant group appear in Table 5.

MT for all components were slower in the DT condition compared to the BL
condition across groups (p<0.01) (refer to Table 5 for individual significance values).
Although all groups appeared to spend a proportionally larger amount of time in Initial
Reach during the DT condition (Figure 20), there was no significant main effect of group
(Table 5). The mod PD group demonstrated slower MT than HC on specific components
including: Coin Lift (F(2,35) =5.282; p<.05); Non-Dominant Transport (F(2,35) = 6.791;
p<.01), Dominant Transport (F(2,35) =6.379; p<.01) and Coin Release (F(2,35) = 6.302;
p<.01). The mild PD group only demonstrated slower MT than the HC for the Non-
Dominant Transport component (F(2,35) = 6.791; p<.05) (Figure 20). No significant
differences were found between the mild and moderate PD groups for either MT or %MT
across all movement components (p>0.05).
### Table 5. Movement Component Times for All Groups

<table>
<thead>
<tr>
<th></th>
<th>Healthy Controls</th>
<th>mild PD</th>
<th>moderate PD</th>
<th>Condition Effect: BL vs DT</th>
<th>Group Effect: HC vs mild PD</th>
<th>Condition x Group Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Reach</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.43 (0.19)</td>
<td>0.48 (0.18)</td>
<td>0.75 (0.35)</td>
<td>185.18 <strong>0.000</strong></td>
<td>0.85</td>
<td>0.435</td>
</tr>
<tr>
<td>Dual Task</td>
<td>1.62 (0.40)</td>
<td>1.74 (0.62)</td>
<td>1.68 (0.71)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coin Lift</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.47 (0.12)</td>
<td>0.54 (0.14)</td>
<td>0.67 (0.25)</td>
<td>9.71 <strong>0.004</strong></td>
<td>5.28</td>
<td>0.010</td>
</tr>
<tr>
<td>Dual Task</td>
<td>0.55 (0.20)</td>
<td>0.63 (0.17)</td>
<td>0.81 (0.32)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Dominant Transport</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.23 (0.34)</td>
<td>0.25 (0.80)</td>
<td>0.42 (0.17)</td>
<td>21.78 <strong>0.000</strong></td>
<td>6.79</td>
<td><strong>0.003</strong></td>
</tr>
<tr>
<td>Dual Task</td>
<td>0.34 (0.95)</td>
<td>0.53 (0.22)</td>
<td>0.50 (0.24)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bilateral Transfer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.23 (0.48)</td>
<td>0.23 (0.53)</td>
<td>0.24 (0.74)</td>
<td>20.15 <strong>0.000</strong></td>
<td>0.123</td>
<td>0.885</td>
</tr>
<tr>
<td>Dual Task</td>
<td>0.32 (0.14)</td>
<td>0.30 (0.10)</td>
<td>0.31 (0.85)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dominant Transport</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.30 (0.48)</td>
<td>0.41 (0.79)</td>
<td>0.56 (0.31)</td>
<td>13.65 <strong>0.000</strong></td>
<td>6.38</td>
<td><strong>0.004</strong></td>
</tr>
<tr>
<td>Dual Task</td>
<td>0.43 (0.13)</td>
<td>0.56 (0.16)</td>
<td>0.59 (0.16)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coin Release</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.34 (0.89)</td>
<td>0.40 (0.12)</td>
<td>0.50 (0.14)</td>
<td>30.56 <strong>0.000</strong></td>
<td>6.3</td>
<td><strong>0.005</strong></td>
</tr>
<tr>
<td>Dual Task</td>
<td>0.52 (0.18)</td>
<td>0.69 (0.30)</td>
<td>0.77 (0.28)</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

All group values are shown mean(SD).
Figure 20. Individual Movement Components by Conditions: MT. Component movement times are compared across groups between baseline (BL) and dual task (DT) conditions and presented on individual plots for: Initial Reach, Coin Lift, ND Transport, Bilateral Transfer, D Transport, and Coin Release. Error bars indicate standard deviation. Main effect of condition is displayed in red below the x-axis. Significant between group differences noted on individual plots.

Percentage of time spent in each movement component was calculated as a function of the total time of each coin transfer. Percentage of movement may indicate a strategy shift in movement execution, where the aforementioned MT may simply be an indication of overall speed. All components except for Coin Release demonstrated significant %MT differences from BL to DT condition (p<0.001) (see Table 6). However, not all component percentages demonstrated similar directional change. Percentage of time spent in Initial Reach increased for all participants from BL to DT (F(1,35) = 235.151; p=.001). Percentage of time spent in Coin Lift , F(1,35) =58.930; p<.001), ND Transport, (F(1,35) =23.1; p<.001), Bilateral Transfer, (F(1,35) =15.7; p<.001), and D Transport,
Table 6. Movement Component Percentages for All Participant Groups

<table>
<thead>
<tr>
<th></th>
<th>Healthy Controls</th>
<th>mild PD</th>
<th>moderate PD</th>
<th>Condition Effect: BL vs DT</th>
<th>Group Effect: HC vs mild PD</th>
<th>Condition x Group Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percentage</td>
<td>Percentage</td>
<td>Percentage</td>
<td>$F_{(2,35)}$</td>
<td>$p$</td>
<td>$F_{(2,35)}$</td>
</tr>
<tr>
<td><strong>Initial Reach</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>21.2(7.7)</td>
<td>19.9(6.1)</td>
<td>23.0(5.8)</td>
<td>235.2</td>
<td><strong>0.000</strong></td>
<td>1.07</td>
</tr>
<tr>
<td>Dual Task</td>
<td>42.8(4.4)</td>
<td>38.5(6.5)</td>
<td>35.3(8.2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coin Lift</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>23.3(5.1)</td>
<td>22.2(4.5)</td>
<td>21.5(4.6)</td>
<td>58.9</td>
<td><strong>0.000</strong></td>
<td>0.23</td>
</tr>
<tr>
<td>Dual Task</td>
<td>14.5(4.3)</td>
<td>14.7(4.1)</td>
<td>17.6(6.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Non-Dominant Transport</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>11.8(1.9)</td>
<td>14.7(2.9)</td>
<td>13.5(3.0)</td>
<td>23.1</td>
<td><strong>0.000</strong></td>
<td>6.6</td>
</tr>
<tr>
<td>Dual Task</td>
<td>9.0(2.0)</td>
<td>11.9(3.4)</td>
<td>10.3(2.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bilateral Transfer</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>11.3(1.9)</td>
<td>9.5(1.5)</td>
<td>8.1(2.4)</td>
<td>15.7</td>
<td><strong>0.000</strong></td>
<td>5.0</td>
</tr>
<tr>
<td>Dual Task</td>
<td>8.8(4.3)</td>
<td>6.8(1.8)</td>
<td>7.1(2.7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dominant Transport</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>15.3(2.7)</td>
<td>16.9(3.0)</td>
<td>17.0(4.6)</td>
<td>57.2</td>
<td><strong>0.000</strong></td>
<td>1.3</td>
</tr>
<tr>
<td>Dual Task</td>
<td>11.3(2.6)</td>
<td>12.7(3.6)</td>
<td>12.2(2.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coin Release</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>16.8(3.5)</td>
<td>16.1(3.6)</td>
<td>16.5(4.3)</td>
<td>3.6</td>
<td>0.067</td>
<td>0.53</td>
</tr>
<tr>
<td>Dual Task</td>
<td>13.5(2.9)</td>
<td>15.1(4.4)</td>
<td>16.4(5.1)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All group values shown as mean(SD).
(F(1,35) = 57.2; p<.001), decreased for all participants from BL to DT. Finally percentage of time spent in Coin Release did not change from BL to DT (F(1,35) =3.6; p=.067).

There was a significant main effect of group for Non-Dominant Transport (F(1,35) =23.08, p<0.01) and Bilateral Transfer (F(1,35)=15.66, p<0.01) in that HC showed a lesser %MT spent in ND Transport compared to individuals with mild PD (F(2,35)=6.65, p<0.01). Additionally, HC demonstrated a significantly greater decrease in %MT spent in Bilateral Transfer than did individuals with mod PD (F(2,35)=5.02, p<0.05).

Although all groups spent a greater amount of time in DT Initial Reach compared to BL, HC spent a significantly greater %MT than did individuals with mod PD. Post Hoc analysis revealed no significant group differences during baseline condition but did identify a significant difference between healthy controls and mod PD in the dual task condition (F(2,35)=4.19, p<0.05), potentially indicating a different movement strategy executed between these two groups as a result of the increased cognitive load associated with the DT condition (Figure 21).
Figure 21. Individual Movement Components by Conditions: %MT. Percentage of time spent in each movement component as a function of the total time of each coin transfer are compared across groups between baseline (BL) and dual task (DT) conditions and presented on individual plots for: Initial Reach, Coin Lift, ND Transport, Bilateral Transfer, D Transport, and Coin Release. Error bars indicate standard deviation. Main effect of condition is displayed in red below the x-axis. Significant between group differences noted on individual plots.

Correct Alphabet Letter Recitation

As an attempt to identify execution strategies that might account for the %MT difference noted between HC and mod PD groups during DT Initial Reach, we identified the movement component(s) during which each correct letter was recited. If two components overlapped during the letter recitation (i.e. coin #1 - Coin Release with coin #2 – Initial Reach), that letter was attributed to both phases. Figure 22 illustrates the distribution of correct letters recited across the six movement components (this was calculated as a percentage by taking the number of letters cited in a given movement component divided by the total, multiplied by 100). HC recited the majority of their
correct letters (61.6%) during Initial Reach and Coin Release compared to individuals with mod PD who distributed recitation of their correct letters more evenly across all movement components, however, these differences were not statistically significant (p>0.05).

Figure 22. Distribution of Correct Letter Recitation across Each Movement Component. The six movement components, indicated by color, are marked with the percentage of correct alphabet letters recited during that individual DT movement component. Each individual bar represents a participant group (HC, mild PD, mod PD). Demonstrating, for example that HC participants recite 61.6% of their correct letters during Initial Reach and Coin Release. The mild PD group demonstrates a similar letter recitation strategy to the HC, however those in the mod PD present with a different pattern of letter recitation.
The C3t Baseline is a Reliable and Valid Measure of Bimanual Hand Function.

This study was the first to evaluate the C3t test of upper limb function and dual task assessment in a cohort of individuals with Parkinson’s disease. The C3t demonstrated good test-retest reliability in the two test conditions requiring less cognitive load and strong content validity as a measure of manual dexterity when compared to a gold standard assessment of manual dexterity (the 9HPT). A standardized assessment of bimanual dexterity does not exist for Parkinson’s disease and the C3t may be a useful measure to identify performance decline that may occur with neurodegeneration of the basal ganglia-cortical-thalamic loops seen with disease progression or as a means to track improvement that may follow a medical or therapeutic intervention.

PwPD demonstrate deficits in multiple domains of unimanual hand function including slow grip initiation, prolonged transition between grip/lift phases, delay between first digit contact and object lift (Ingvarsson et al., 1997), and difficulty with object release when instructed to move quickly (Gordon, 1998). Studies have also detected bimanual impairments in PwPD, although findings have focused primarily on an inability to maintain “anti-phase” coordination in comparison with “in-phase’ coordination activities in laboratory based tasks (Almeida, Wishart, & Lee, 2002; Byblow, Summers, Lewis, & Thomas, 2002; Ponsen et al., 2006). Alberts and colleagues (1998) simulated a bilateral reach to grasp task where PwPD executed bilateral reach and grasp activities for objects with different accuracy demands. Once
grasped, the objects were pulled apart, requiring dynamic coordination of grip and load forces. Findings indicated PwPD decrease degrees of freedom during this task implementing similar reaching for two unequal objects and thus simplifying the task (Alberts, Tresilian, & Stelmach, 1998). Similar to this C3t study, Alberts and colleagues assessed bilateral upper extremity function though a simulated functional task (Alberts et al., 1998).

While there are standardized assessments that evaluate unimanual dexterity, only two have been studied in PwPD. Both of the standardized assessments used in PwPD involve measurement of coordination and dexterity using small peg manipulation. In the Purdue Pegboard Test (PPBT), small metal pegs are picked up individually and placed into 2 vertical rows of 25 holes as quickly as possible, measuring the number of pegs placed in 30 seconds (Tiffin & Asher, 1948). The 9 Hole Peg Test (9HPT) involves individually lifting 9 pegs from a dish, placing them into 9 holes on a board and then individually removing them as quickly as possible, with an outcome measure of total time (Grice et al., 2003). The PPBT was found to differentiate between PwPD and healthy controls but has not been assessed for reliability and validity in this population (Haaxma et al., 2010; Proud & Morris, 2010; Růžička et al., 2016). The 9HPT was found to be a reliable and valid measure in PwPD (Earhart et al., 2011). Along with developing 9HPT normative data for PwPD (categorized by age and disease severity), Earhart et al. (2011) found this unimanual assessment differentiated between PwPD and HC (although it was not assessed for sensitivity to disease severity). We found the C3t baseline condition to be highly correlated with the 9HPT for dominant and non-dominant hands, indicating the C3t is a good measure of manual dexterity. However, the C3t may be a more complete assessment of upper limb function due to its ecological validity (simulation of a functional coin manipulation task), its increasing levels of complexity challenging individuals at differing levels of ability, and its requirement of bimanual coordination for successful completion, requiring more complex coordination processes than a unimanual task alone.
While assessment of unilateral hand function is important, bimanual coordination is necessary for the majority of activities of daily living. The neural mechanisms underlying bimanual coordination are more complex than unimanual control, requiring the control and coupling of two limbs compared to unilateral control (Kraft et al., 2007; Song, Yoo, Park, & Park, 2010). Although the neurophysiologic processes for bimanual coordination are not completely understood, the supplementary motor area (SMA) is thought to be involved in the integrated activity of the two limbs (Kraft et al., 2007; Song et al., 2010). The SMA, along with the basal ganglia are involved in the neurophysiological motor loop responsible for the control of coordinated movement, including bimanual dexterity (Magrinelli et al., 2016). Identification of these bimanual coordination deficits in PwPD may be an additional impairment indicator that should be further evaluated in PwPD and may be sensitive to disease severity.

To date, no studies have evaluated bimanual upper extremity functional assessments in PwPD. There are currently four standardized bimanual upper extremity assessments designed for impaired populations: 1) the Both Hands Assessment (BoHA) to assess children with cerebral palsy (Elvrum, Zethræus, Vik, & Krumlinde-Sundholm, 2018); 2) the BiManual Dexterity Assessment (Tesio et al., 2016); the 3) Sequential Occupational Dexterity Assessment (SODA) for individuals with Rheumatoid Arthritis (Van Lankveld et al., 1996); and 4) the Adult-Assisting Hand Assessment Scale for individuals with stroke (Krumlinde-Sundholm, Lindkvist, Plantin, & Hoare, 2019). None of these assessments are commonly used in rehabilitation clinics and none have been evaluated in a PD population. Knowing that the C3t (baseline condition) has shown to be a reliable and valid assessment of bilateral manual dexterity, clinical use of this tool has the potential to capture an area of functional ability that has yet to be measured reliably in PwPD.

While the C3t baseline was found to be a reliable and valid assessment of bimanual dexterity, the DT condition score did not prove to be a reliable dual task measure in PwPD. The C3t was created to assess upper limb function and dual task
ability in individuals with Huntington’s disease (HD) (Clinch, 2017). Similar to the current findings, Clinch (2017) found the C3t baseline score and total time demonstrated good test-retest reliability, and the complex condition score and total time showed moderate test-retest reliability. Similar to our findings, Clinch also found the DT score to have poor reliability and the DT total time to have good reliability and concluded that the C3t total time was a more reliable measure than the C3t score (Clinch, 2017). However, considering the DT performance as simply a measure of time with no consideration for errors fails to identify a critical feature of this task performance. Analysis of dual task performance must consider the reciprocal effect of each task on the other (McIsaac et al., 2015). In the current study, that involved analysis of changes in both cognitive and motor performance.

Healthy individuals have limits on their ability to process information (Marois & Ivanoff, 2005). When performing two task simultaneously, it is these capacity limitations that impact an individual’s ability to allocate adequate attentional resources across multiple tasks successfully (McIsaac et al., 2015). Performance decrements associated with capacity limits may be even more problematic in individuals with neurodegenerative diseases such as HD and PD (Fritz, Cheek, & Nichols-Larsen, 2015). The purpose of developing a standardized dual task assessment for patient populations is to be able to understand how individuals are choosing to allocate their limited resources in their attempts to perform both tasks successfully. Such a dual task assessment could be evaluative but also be used as an outcome measure to identify change over time. Execution errors made during a dual task scenario result as the cost of adding the secondary task and must be analyzed as part any performance outcome.

We hypothesized that the C3t would demonstrate good test retest reliability for all conditions, however the dual task condition had poor reliability. The C3t dual task condition introduced high levels of task novelty and task complexity (McIsaac et al. 2015). The novelty and complexity of the dual task condition necessitated increased attentional load and optimal allocation of attentional resources to successfully execute
this specific combination of cognitive and motor tasks. This proved challenging for participants across all three groups as evidenced by their decreased performance scores and their mutual interference prioritization profiles. Individual strategies for approaching resource allocation in the face of high task novelty and complexity may vary during task execution, thus repeated performance may not prove to be reliable. An individual’s strategy from trial to trial may vary in that they may demonstrate a different priority pattern between the cognitive and motor tasks, or their physical performance may vary due to a variety of performance variables (Magill & Anderson, 2017). Change in prioritization or individual performance variables on repeated trials may increase variability in task execution, negatively affecting reliability (Clinch, 2017).

The results of this study are in line with previous research that suggests it may be difficult to demonstrate reliability in dual task measures in PwPD. Strouwen et al. (2016) evaluated PD participants walking while performing three different secondary tasks: 1) a backward digit span task; 2) an auditory Stroop test; and 3) a mobile phone task (considered the most complex of the three testing conditions). Overall, they found the motor measures (gait determinants) to be more reliable than the cognitive test measures. They also reported lower correlations with the more complex task (mobile phone task). Specifically, simple task (digit span and Stroop) gait measures (speed, stride length, cadence, swing percentage and stride time) and postural control measure (stride width) demonstrated test-retest ICC ranging from 0.89 – 0.95 indicating good reliability, while the cognitive measure (errors) demonstrated test-retest ICC ranging from 0.41-0.62, demonstrating poor – moderate reliability. While, the more complex task (mobile phone) measures of gait and postural control demonstrated lower test-retest ICC ranging from 0.72-0.89 indicating good reliability, the cognitive measure: errors demonstrated a poor test-retest with ICC as low as 0.21. (Strouwen, Molenaar, Keus, Münks, Bloem, et al., 2016). These findings align with the current study, which found good motor test-retest reliability under the simple test conditions but decreased motor test re-test reliability as task complexity increased.
However, in contrast to the Strouwen study, which found cognitive measures to have poorer reliability than gait measures, in this study, the cognitive test ICC values were moderately reliable and higher than the motor findings. Strouwen et al. (2016) hypothesized that their cognitive reliability was lower than motor because gait was a habitual task and the cognitive tasks more novel. Perhaps in this study, recitation of every other letter of the alphabet was more familiar than the novel, coin transfer task leading to a higher level of cognitive task reliability.

Research has shown that in dual task situations with decreased novelty and complexity, test-retest reliability may be achievable in both motor and cognitive tasks in PwPD (Bloem, Valkenburg, Slabbekoorn, & Willemsen, 2001; Strouwen et al., 2016). However, as tasks become more complex or increasingly novel, task execution is more challenging in PwPD, increasing task variability and making reliability more difficult to achieve (Strouwen et al., 2016). The high novelty of the C3t task and the high complexity of the DT condition are so challenging and the variability of individual approach to the task is so great, that the test in its current configuration is not reliable. The C3t DT needs further development to identify optimal levels of motor and cognitive challenge that will lessen the complexity, making it more achievable. Similarly, consideration of an alternate scoring mechanism that consistently and reliably captures performance time while also accounting for task errors may improve overall DT test-retest reliability.

The current scoring system requires the examiner to be able to identify transfer, rule and dropped coin errors during task execution as well as attend to alphabet letters recited correctly in order to calculate the DT total score. This places a high attentional burden on the examiner and it may not be possible to gather all required information without recording performance for later analysis. An assessment tool requiring such a high clinician burden may not be ideal for clinical assessment scenarios. In an attempt to incorporate the errors made into the time measure (modified time), for ease of examiner burden we added penalty time (5 sec.) to the overall performance time for each transfer, rule or drop error made. This method of adding penalty time for errors
made has been used in other standardized assessments (Aaron & Stegink Jansen, 2003; Arbuthnott & Frank, 2000). Test-retest reliability was assessed using this modified time measure, and all three testing conditions (BL, Complex and DT) demonstrated poor reliability. This initial attempt to generate a composite of time and error was not successful and further investigation is required.

**C3t Performance Scores Can Distinguish Between Healthy Control and PwPD.**

Performance scores on the C3t declined from single to complex to dual task conditions for all participants indicating that each condition provided an increasing challenge and was not a duplication of the previous condition. A task is considered complex if it has: 1) a variety of solutions; 2) a high cognitive load - meaning demands placed on memory and processing capacity; and /or 3) several components or degrees of freedom involved in task execution (Levac, Huber, & Sternad, 2019; McIsaac et al., 2015; Sternad, Huber, & Kuznetsov, 2014; Van Merrienboer, Kester, & Paas, 2006). In the current study, the C3t dual task condition meets all of these criteria to be considered a complex task. The C3t scores were significantly lower across all conditions for PD participants compared to the HC. Increasing complexity may have been related to the increased cognitive load associated with each new condition. The increased cognitive load in the C3t DT condition required participants to allocate their attention between the two tasks (McDowd, 2007). Performance on the C3t dual task was significantly more challenging than complex and baseline tasks across all three groups. When comparing performance across disease severity, healthy controls performed significantly better than the moderate PD group across all conditions and mild PD performed significantly better than mod PD during baseline and complex conditions, indicating that C3t baseline and complex conditions were sensitive to disease severity. The dual task condition, although able to differentiate between HC and PwPD, was not sensitive to disease severity. This may be due to the
high level of task novelty and complexity making the task challenging for all PwPD, impacting performance and negating difference between mild and mod PD groups. We hypothesized that the dual task condition of the C3t would be the only condition that would be sensitive enough to distinguish between HC and mild PD participants, who are in early disease stages. The motor and cognitive symptoms associated with PD develop very slowly as basal ganglia degeneration progresses (Bezard, Gross, & Brotchie, 2003). As the result of this slow progression, PwPD slowly develop compensations to overcome the developing impairments (Bezard et al., 2003), providing an explanation for why the basic motor and cognitive assessments available to rehabilitation professionals may not pick up the subtle changes in early PD compared to HC. However, it has been suggested that the combination of motor and cognitive tasks performed simultaneously provide the challenge needed to identify possible deficits in early PD (Fuller et al., 2013). Post hoc analyses revealed that the differences between healthy controls and individuals with mild PD at the dual task level was not significant at p=0.07. Although not significant, there is a large effect size based on Cohen’s d between HC and mild PD on dual task ($\mu^2 = 0.987$) indicating a strong relationship between the two variables (Lakens, 2013). The dual task C3t, however, had poor reliability thus limiting the interpretation of these findings.

**Factors Related to C3t Dual Task Performance**

In order to determine which demographic, motoric or cognitive characteristics related to successful performance on the C3t conditions, linear stepwise regression analyses were executed entering variables that showed significant correlation with each of the C3t condition scores. It was hypothesized that certain representative variables would predict outcome on all C3t condition scores: MDS-UPDRS III as an indicator of PD disease severity, Stroop and/or Trail Making B as an indicator of executive function and a manual dexterity assessment as a measure of hand function.
However, this was not the case. Variables predicting outcome on the C3t baseline condition included the 9HPT dominant and non-dominant hand (a measure of dexterity). On the simplest version of this assessment, these measures of dexterity accounted for 74% of the variance. The MDS-UPDRS III – a motor measure of disease severity was found to be collinear with the 9HPT and was excluded. It is understandable that 74% of the variance in this C3t baseline task, which proved to be a valid measure of manual dexterity, should be predicted manual dexterity measures.

For the C3t complex condition, the 9HPT dominant and non-dominant hands along with the Stroop Test predicted 65% of the variance thus, as the task complexity increased by adding a cognitive component, this task was predicted by both motor and cognitive measures. The only predictor of C3t dual task performance was the Stroop test, which accounted for 23% of the variance. Attending to both the motor and cognitive components of the dual task condition required switching attentional focus between the two tasks or inhibiting attention towards one task, allowing focus towards the other. The Stroop assessment is a measure of these executive function abilities. Although only accounting for a small portion of the variance, it is logical that performance on the Stroop test would predict performance on the C3t dual task condition. As the C3t task conditions became more complex, it became harder to predict the outcome, leaving a large portion of variance unexplained and perhaps lending itself to the idea that there may be a unique construct underlying dual task function. Under the high challenge of this dual task condition, participants attempted many different strategies to succeed; this was obvious in the high levels of variability surrounding the C3t dual task scores. The C3t dual task condition also demonstrated poor test re-test reliability, meaning participants did not have the same outcome each time. If there are large differences in performance execution, it is reasonable to assume predicting performance outcome would be difficult.

In an earlier (prototype) version of the C3t assessment, Clinch (2017) included a dual task condition with less complexity. In this earlier version, called the Money Box Test, the values on the dual task coins had the same values as complex condition
coins (200, 100, 50, 20, 10, 5, 2, 1), in addition, the cognitive task involved reciting the complete alphabet (Clinch, 2017) instead of every other letter of the alphabet (as in the current study). Using the Money Box Test for her initial study, Clinch found components of the Unified Huntington’s Disease Rating Scale – Total Motor Score (pronation, supination and bradykinesia) best predicted C3t dual task performance in individuals with Huntington’s disease, however, she did not include cognitive measures in her regression analysis (Clinch, 2017; Clinch et al., 2018). These findings support the idea that there may be a more optimal combination of motor and cognitive tasks that would make the C3t dual task condition a more reliable assessment. During early pilot data, collected by this researcher and using the Money Box Test, participants appeared to become very familiar with the coin values, having experienced them three times, thus to make the dual task condition more challenging, the cognitive task was modified to recitation of every other letter of the alphabet. In hindsight, it appears that the combination of a more challenging cognitive task and the modified dual task coin values in the final version of the C3t (see Figure 3), made this third condition extremely complex. None of the studies testing upper extremity dual task performance in PwPD (Kalirathinam & Vaidya, 2014; Pradhan et al., 2010; Proud & Morris, 2010; Teixeira & Alouche, 2007) evaluated which factors were associated with successful DT performance, thus it is difficult to predict the generalizability of these findings.

Similar to the current study finding that a motor measure predicted the motor dual task outcomes, dual task research that evaluated walking combined with a secondary task, focused on the impact of the secondary task on gait speed (Raffegeau et al., 2019). Kelly et al. (2012) found that motor factors related to disease severity (MDS-UPDRS III, H&Y scale and bradykinesia) were associated with a decrease in gait speed under DT conditions (Kelly et al., 2012). On the cognitive side, reduced measures of set shifting, verbal fluency and attention were found to be associated with a decreased DT gait speed in PwPD (Plotnik, Dagan, Gurevich, Giladi, & Hausdorff, 2011; Strouwen, Molenaar, Keus, Münks, Heremans, et al., 2016). The DT walking
studies mentioned above indicate that certain variables do predict certain outcomes, however, not all regression model specifics were included in their results. Without understanding the % variance attributed to each variable, interpretation of their impact is limited (Plotnik et al., 2011). Although limited data is available reporting association of specific variables to related task variance, instances where this data is presented, the resulting variance explained accounts for a small percentage of the whole (Plotnik et al., 2011).

**C3t Affects Both Cognitive and Motor Task Performance**

Participant’s cognitive and motor dual task interference values were plotted as x,y coordinates onto a prioritization profile plot using a model designed to characterize patterns of cognitive-motor dual task interference based on previous work (Plummer et al., 2015) (Figure 11). While this analysis is limited due to the poor reliability of the dual task C3t, it is still instructive to evaluate the cost prioritization utilized by participants. Understanding prioritization of one task over the other can give insight into the strategy used to accomplish the goal. Shumway-Cook et al. (1997) discussed the idea that when two motor tasks are performed together, maintenance of posture should be the priority for safety reasons and coined the term “posture first” (Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). However, other research has indicated that “posture first” is not always a strategy chosen consistently. Rather, allocation of attention during dual task performance is not first or second or invariant, but a flexible continuum (Kelly et al., 2013; McIsaac & Benjapolakorn, 2015; Shumway-Cook et al., 1997; Yogev-Seligmann, Rotem-Galili, Dickstein, Giladi, & Hausdorff, 2012). Individuals may focus their attention on one task, or they may attempt equal prioritization between the two tasks, or some continuum in between. This allocation of resources can be flexible and may be based on specific aspects of the task, the environment, and/or characteristics of the individual (Kelly et al., 2013; McIsaac & Benjapolakorn, 2015). In the current study,
during the C3t dual task, the majority of participants falling into quadrant IV (Figure 16) indicated an attempt to focus on both tasks, resulting in a performance decrement to both. Yet within the mutual interference quadrant (Figure 17), only 10% demonstrated an equal priority, falling right along the dashed line, while 59% tended toward a motor priority while 31% tended toward a cognitive priority. Visualizing how far individual participants fell from the equal priority line indicated where on the continuum between motor and cognitive priority each subject landed. Comparatively, during the dual task TUG, participants fell into all four quadrant plots (Figure 18) demonstrating a much wider dispersion along the motor/cognitive priority continuum. The high novelty and complexity of the C3t dual task, did not allow successful completion of either the cognitive or motor task. However, with the lower novelty and complexity of the dual task TUG, some participants were able to allocate attentional resources allowing successfully complete either the cognitive or the motor task at the expense of the reciprocal task (Figure 18, quadrants I or III) or both tasks (Figure 18, quadrant II).

Individuals with PD have difficulty allocating their attentional resources optimally for the specific situation at hand. Bloem et al. (2006) suggested that PwPD use a “posture second” strategy, choosing the secondary task over the primary task even when safety is at risk (Bloem, Grimbergen, van Dijk, & Munneke, 2006b). However, Bloem (2006) concluded that all people including those with PD can approach dual task challenges differently and their strategy may be influenced by age, disability, illness or prior experience. Healthy adults may be able to recognize the difficult aspect of dual task performance and choose to prioritize the majority of their attention to that aspect of the task (Bloem et al., 2006b). Others may adapt their walking to be able to accommodate performance of the secondary task (Wild et al., 2013) and still others may focus on the secondary task at the expense of the primary task. In the current study, more PD participants tended towards a motor priority than a cognitive priority in both the C3t and TUG dual tasks, however, some PwPD did
prioritize the cognitive task. This prioritization choice of focusing on the secondary
cognitive task over the motor task is seen in of PwPD and is worthy of further study.

For healthy adults, walking is considered an automatic task, meaning it does not
require high levels of attentional demand. When performing an upright dual task in a
familiar situation, most healthy adults are able to give adequate attentional resources
to the secondary task because walking typically requires limited attention (Magill &
Anderson, 2017). In PwPD, the motor symptoms of PD (bradykinesia, freezing of
gait, rigidity) make walking more difficult, requiring renewed attentional allocation to
the performance of walking (Wu, Hallet & Chan, 2015). This then limits attention
available to a secondary task. With a wealth of research examining dual task
prioritization in upright tasks, there is limited data examining dual task prioritization
in seated tasks (such as driving), where the heavy postural control requirement is
removed from the motor task, but the attentional demand remains.

McIsaac and Benjapalakorn (2015) evaluated dual task effects and attention
allocation patterns in a novel seated dual task combining upper and lower extremities
under two levels of task difficulty. They found healthy young adults demonstrated
decreased levels of performance in all aspects of both tasks when performed under
dual task conditions compared to single task conditions. They found a “trade-off”
between arm and foot tasks, suggesting the participants did not have adequate
attentional resources for successful completion of both tasks simultaneously. Rather,
participants may have focused on which limb task had the greater momentary priority
and then switched back to the other limb’s task when necessary with subsequent back
and forth alternations as appropriate. (McIsaac & Benjapalakorn, 2015)

It is reasonable to consider that participants may exhibit a different priority with
seated and standing tasks. Prioritization profiles were generated for the dual C3t and
TUG tasks. We hypothesized that PwPD would prioritize motor performance over
cognitive performance on the dual task TUG, where the task involves a postural
component and attention allocated to walking which has become less automated.
Conversely, participants would prioritize cognitive performance over motor
performance on the C3t dual task where the postural demand is reduced. Results showed that all but one participant (mod PD) demonstrated mutual interference on the C3t task (Figure 16, quadrant IV). Even within the mutual interference quadrant, it is possible to see a cognitive or motor priority. If participants were giving equal priority to both cognitive and motor tasks, their performance would fall close to a diagonal line-bisecting quadrant IV (Figure 17). If the performance falls above or below such a diagonal line, this would indicate a prioritization towards the motor or cognitive task even within the mutual facilitation quadrant (McIsaac et al., 2015). Across groups, most participants demonstrated a motor prioritization, while demonstrating a cost on both cognitive and motor tasks (Figure 19). Thus, despite the decrease in postural control demand with the seated C3t dual task, many participants appeared to demonstrate a slight motor priority when performing the dual task C3t. No differences were seen between the prioritization profiles of HC and PwPD. However, some participants with PD prioritized the cognitive task in both the upright and seated situations, suggesting that the choice may be due to individual interactions between each participant, the task and the environment and require further investigation for clarity.

We then plotted a prioritization profile for the TUG performed with a cognitive secondary task, a gold standard measure of upright, dual task function. The cognitive task used during the dual task TUG included reciting every other letter of the alphabet, as in the C3t dual task condition. The prioritization pattern seen with dual task TUG performance is very different from the C3t prioritization profile. While two HC demonstrated a very small mutual benefit, the remainder of the participants exhibited a performance decline in one or both of the DTs. This variety in approach to task prioritization during the dual task TUG was noted across participant groups and was not a product of disease severity.

In an attempt to view the overall task cost/benefit as a point on a continuum, a dual task “total cost” was calculated by summing the motor and cognitive cost/benefit values for each participant (see Figure 9 for calculation). Compared to the TUG, the
C3t had higher total dual task cost with low variability, where the TUG had a low cost but a very high level of variability. The TUG test, comprised of sit to and from stand and walking components is not a highly novel or complex task for any of these adult participants. The low novelty and complexity combined with the fact that participants were not given explicit instruction for task priority, allowed participants to perform the tasks with little dual task cost and to prioritize the tasks based on their internal preferences, which were widely varied. The high level of novelty and complexity inherent in the C3t dual task produced high levels of dual task cost in all participants despite the variability seen in the DT performance scores. This low level of variability in the C3t total cost score indicated that despite the varied strategies participants employed to best accomplish this dual task, their cost values were similar.

The high levels of variability in the dual task TUG total cost measure indicates that there was little consistency in how participants allocated their attentional priority between the motor and cognitive aspects of this task. If the prioritization profile is so different between participants, it may also differ when tested repeatedly for the same participant. Such performance variability could confound the predictability of this test when used to assess change pre and post intervention. Test re-test reliability of the dual task TUG would be needed to determine if this is a reliable outcome measure.

Only one study has looked at test retest reliability for the TUG- cognitive (TUGCOG) (Hofheinz & Schusterschitz, 2010). This study reported good test retest reliability for the TUGCOG with a secondary cognitive task of serial 7 subtractions (ICC 0.94). However, the outcome measure for this test was time and the examiners did not measure the cognitive task outcomes during either single or dual task performance. No comparisons were made to single task performance and dual task cost was not calculated (Hofheinz & Schusterschitz, 2010). Participants could have executed the task in a reasonable time and made many mathematical errors. As mentioned earlier when discussing the C3t assessment based on an outcome measure of time, time without consideration of errors provides an incomplete picture.
The dual task total cost measure was designed for this study and has no comparison in the literature. In order to use this assessment to capture change following an intervention or physiological decline, further study is needed to determine if the dual task TUG demonstrates test retest reliability using the total cost measure as the outcome variable.

**Movement Component Analysis**

Dividing each coin transfer into movement components gave us additional information about how execution strategies used by participants changed with increasing task complexity and provided a window into which components were more difficult for PwPD compared to healthy controls. We hypothesized that longer movement times would be seen between BL and DT conditions for HC and PwPD with greater differences between the groups noted during *Coin Lift*, *Bilateral Transfer* and *Coin Release* secondary to the increased accuracy demands during those components, adding additional task complexity. Additionally, individuals with moderate PD would demonstrate longer movement times during *Coin Lift*, *Bilateral Transfer* and *Coin Release* than those with mild PD.

The six movement components (Table 2) were evaluated in two ways: 1. Time to complete the phase (MT) and 2. Percentage of time spent in each component as a function of the total time of each individual coin transfer (%MT). MT gave a sense of speed for each component, where %MT gave a representation of the individual component against the whole, indicating a potential strategy shift.

Evaluating MT, we noted that regardless of group, all participants were significantly slower in the DT condition compared to the BL condition for all movement components. This effect could be due to the increased task complexity requiring increased cognitive processing across participants. Additionally, for PwPD the increase in movement time could be a result of bradykinesia, defined as slowness of movement (Jankovic, 2008) and/or bradyphrenia (a slowness in thinking or
cognition) (Hanes, Pantelis, Andrewes, & Chiu, 1996; Peavy, 2010). Bradyphrenia has the potential to impact both the motor and cognitive aspects of the task. A greater magnitude of change is noted from baseline to dual task conditions during Initial Reach for all participants. This increase in Initial Reach MT is likely due to the increased cognitive processing required for the dual task. During Initial Reach BL, participants transfer coins in order of coin size and the coins are positioned in size order (largest to smallest-Figure3-A). For this reason, execution of the baseline trials has a low cognitive demand. Conversely, during the dual task trials, the coins are transferred in order of highest to lowest value and these values are placed in a random order (Figure 3-C). Participants must first identify the correct starting coin based on value, while at the same time process the alphabet letters they will recite presenting a higher cognitive processing load upon task initiation. This increased load is evidenced by the increased Initial Reach time for all. Participants with mod PD demonstrated a significant increase in MT during the Coin Lift, Non-Dominant Transfer, Dominant Transfer and Coin Release phases compared to HC, while participants with mild PD only differed significantly from HC during Non-Dominant Transfer.

Although there were no MT component differences between the mild PD and moderate PD groups, some expected and unexpected differences were found between HC and mod PD. When manipulating an object under single task conditions, PwPD demonstrated a prolonged delay between object contact with the first digit and initiation of object lift (Ingvarsson et al., 1997). Hejduková et al. (2003) divided a reach, grasp and transport activity into movement phases and compared the movement phases between PwPD and healthy controls performing a reach, grasp, transport and release task (Hejduková et al., 2003). Their instrumentation allowed division of their task into a greater number of movement phases than this current study. Their “preloading, loading and acceleration” phases together equal Coin Lift. As in the current coin task, PwPD were found to be significantly slower in these phases than HC (Hejduková et al., 2003). Similarly in a study evaluating the effect of dual task on
precision grip compared to a single task in healthy young adults, precision grip preload phase showed significantly longer duration (Guillery, Mouraux, & Thonnard, 2013). The combination of PD-specific impairment coupled with slower precision grip preload for dual tasks likely explain why PwPD demonstrate delays in Coin Lift under dual task conditions.

PwPD have also demonstrated difficulties with manipulation related to release of an object under single task conditions. When moving as fast as possible, PwPD demonstrated a delayed isometric force decrease and a slowed release duration between thumb and finger resulting in a significantly slower object release than HC (Gordon, 1998). During the timed reach, grasp, transport and release task, PwPD also demonstrated a delayed load force along with precision grip release (Hejduková et al., 2003). These object manipulation motor control difficulties combined with the increased cognitive load of the dual task condition may explain the increased Coin Release MT seen in PwPD.

An unexpected finding was increased time PwPD spent in non-dominant and dominant transport compared to HC. Hejdukova et al. (2003) found PwPD to be slower with acceleration and reaching maximal height during object transport. The transport differences were due to decreased velocity and an abnormal velocity profile, demonstrating multiple peaks of low amplitude and resulting in a longer acceleration phase in PwPD, which they attributed to an issue with muscle activation. (Hejduková et al., 2003). Guillery and colleagues described a significant grip force increase during the “hold” phase of a precision lift task under dual task conditions, suggesting that participants adopted that strategy to compensate for dual task interference with the fine adjustment of grip force during the hold phase (Guillery et al., 2013). The same strategy may hold true for transport, during which a subject would maintain optimal grip and load forces on an object over the length of the transport. Knowing that the secondary task may interfere with the maintenance of those forces, the participants with PD may employs a strategy of increasing grip force in preparation for the
cognitive distraction. The additional time required to generate this increased grip force may explain increase in transport times in PwPD.

The percentage of time (%MT) all participants spent in each component changed significantly from baseline to dual task conditions except for Coin Release. From baseline to dual task the %MT spent in Initial Reach increased while the %MT spent in Coin Lift, non-Dominant Transport, Bilateral Transfer, and Dominant Transfer decreased. From baseline to dual task conditions, all groups increased their %MT spent in Initial Reach. HC spent a significantly greater portion of time in this phase than did the mod PD group. As mentioned above the increased dual task cognitive load that disproportionately affected Initial Reach MT is noted with %MT as well. During the dual task trials, participants initiate the reach, then hesitate as they search to identify the highest valued coin to lift first. This is consistent across all participant groups.

Altering the %MT spent in each component might be part of the strategy for task execution. In order to determine if the %MT Condition x Group interaction was the result of a different execution strategy between the groups, we analyzed correct alphabet letter recitation during the cognitive task. We identified the movement components during which every correct letter was recited (Figure 22). HC recited the majority of their correct letters during Initial Reach/Coin Release (frequently overlapping components) compared to the moderate PD group that recited less than half of their correct letters during these same phases. Healthy controls spent an increased %MT in Initial Reach/Coin Release because they adopted a specific strategy to deal with the increased cognitive load introduced in the dual task condition.

Based on these findings, it is possible that by reciting the majority of their correct alphabet letters during Initial Reach/Coin Release, HCs were able to focus their attention on the cognitive component of the dual task during the movement components with low accuracy demands, thus decreased complexity. They could then switch their attention toward movement execution and then back to the cognitive task
in an organized pattern. For this complex task, the HC participants may have attempted to give priority to both components by switching rapidly back and forth between the motor and cognitive tasks. This approach to task execution involves task-switching (Koch, Poljac, Müller, & Kiesel, 2018b; Strobach, Wendt, & Janczyk, 2018). Individuals with moderate PD, known to have difficulty with task switching, do not appear to adopt the same strategy. Rather than citing most letters during the coin release/initial reach, mod PD appeared to recite letters more equally across all movement components, compounding difficulty by adding the cognitive demand of letter recitation to the more complex, higher accuracy demanding movement components (coin lift, bilateral transfer and dominant transport) resulting in performance decline. The pattern seen by the mild PD group is close to that demonstrated by HC. This difference in strategy between HC and mod PD groups, may be due an executive function difficulty with task switching (Dirnberger & Jahanshahi, 2013; Kudlicka, Clare, & Hindle, 2011), where PwPD are unable to rapidly alternate between different course of thought or action. An additional explanation may be difficulty scheduling of their attention shifts (Janssen et al., 2012). Janssen and colleagues identified strategies participants used to determine when to shift their attention back and forth between dual tasks. They hypothesized that participants would chunk task information and switch attention between tasks when there was a “natural break point” (Janssen et al., 2012). Using a driving simulation task while simultaneously dialing a mobile phone number, they determined that participants do schedule their attentional shifts during natural task dependent break points and priority objectives influenced task performance. Janssen and colleagues were able to determine an “optimal performance trade-off curve” for their task and found that participants who shifted task attention at these natural break points (a phone number chunk boundary or at the beginning of a series of repeating digits) came close to optimal task performance (Janssen et al., 2012). It is possible that the optimal focus for letter recitation was during Coin Release, which may overlap with Initial Reach.
Healthy controls in this current study appear to have identified a natural break point, choosing to shift attention to letter recitation during Initial Reach/Coin Release. Two overlapping components, which do not appear to require a heavy attentional load. They then quickly switch attention back to the motor task for Coin Lift, Bilateral Transfer and Dominant-Transfer, the motor components with greater accuracy demands, which require an increased attentional load. They were able to self-determine this “natural break point” (Janssen et al., 2012). The mild PD used the pattern identified in the HC group. Mod PD participants appear unable to identify this natural break point or are unable to flexibly shift their attention back and forth between the cognitive and motor tasks. They instead may have attempted to devote attention to both the motor and cognitive tasks, which resulted in correct letter recitation across all movement components. The inability to switch optimally between tasks may have led to performance deterioration compared to the HC.

**Conclusions**

In conclusion, the C3t baseline score proved to be a valid measure of bimanual dexterity with good test re-test reliability found for baseline and complex conditions. Being able to use the baseline and complex conditions as reliable measures of bimanual dexterity and coordination may be useful for measuring change in a clinical trial or therapeutic intervention aimed at improving hand function in PwPD. Although the C3t dual task condition was not found to be reliable, this may be due to the high level of task novelty and complexity. Further evaluation is required to determine the optimal task levels of cognitive and motor challenge needed to make this dual task more responsive to differing ability levels and to change over time.

Performance scores on all C3t conditions were able to differentiate between healthy controls and PwPD and the baseline and complex conditions were sensitive to disease severity, differentiating between mild and mod PD. None of the C3t conditions were sensitive enough to differentiate between individuals in the early
stage of PD (mild PD) and healthy controls. This differentiation was only hypothesized to be present in the C3t dual task condition and the reliability issues with this condition may have negated these findings.

Motor (9HPT) measures were found to predict performance on the C3t baseline condition, accounting for a large percentage of the task variance and further supporting its use as a functional upper limb assessment in PwPD. Motor (9HPT) measures along with cognitive measures (Stroop) were found to predict performance on the C3t complex condition, reinforcing the idea that there was an increased cognitive demand to the task. Only a single cognitive measure (Stroop) was found to predict a small percentage of the variance on the C3t dual task condition confirming that executive function is a component of dual task ability. However, the poor reliability of the C3t dual task condition, indicating participants demonstrated different performance levels over time, may explain why it was too difficult to predict influencing factors on dual task performance.

Different prioritization profiles were observed between the C3t and TUG dual tasks indicating differences in cost and prioritization between the two tasks. It is difficult to determine if these differences were due to the postural demands between the seated and upright tasks or the differences in task novelty and complexity levels. Further development of the C3t dual task condition is required and additional comparison between tasks necessary before such a finding would be obtainable.

Breaking the coin transfer trials into movement components showed movement component times were longer for all participants when dual task demands were imposed. Movement times for the components with increased accuracy demands were significantly different between healthy controls and mod PD reinforcing that dual task requirements place additional demands on an already limited attentional system and this coupled with dexterity issues seen in PwPD can limit dual task function in daily life.

This study demonstrated that the baseline condition of the C3t is a valid and reliable upper extremity assessment that can be used as a measure of manual dexterity.
in PwPD. This upper limb assessment has the potential to identify a decline in upper extremity motor function that accompany the neurodegeneration in PD or an improvement in function resulting from medical or rehabilitative intervention. This ability to measure manual dexterity with the performance of a bimanual task, is new to the field of rehabilitation. The complex condition of the C3t demonstrates good test re-test reliability and provides an increased level of complexity over the baseline condition providing both cognitive and motor challenge. The C3t dual task performance score was not found to be a reliable measure of dual task ability in PwPD. Although the total time measure of C3t dual task performance was found to be a more reliable outcome measure for this assessment, total time does not account for either motor or cognitive errors made during task execution. In a scenario where a participant moved very quickly while making multiple errors, relying on their total time as an outcome measure ignores a critical aspect of task performance, delivering an incomplete performance picture. As a result, the C3t dual task condition, in its current configuration, should not be used in clinical settings for dual task assessment in individuals with PD. Further test development and evaluation, including consideration of alternative cognitive tasks, complexity of numbers on the dual task coins, and alternative scoring mechanisms, must be undertaken prior to reliable and valid use of this tool in PwPD.

Study Limitations

The limitations of this study must be considered. The sample size was small, the C3t dual task complexity was too great and the C3t task score may be problematic. A larger sample size would be beneficial for future reliability and validity studies. The C3t outcome measures need re-evaluation. Clinch (2017) indicated that the primary outcome measure was task time, however, she developed the accuracy measures and total task score as she noted participants making errors that were not being captured by the time measure alone. Gathering data for the C3t baseline and
complex conditions are manageable for one clinician within the actual test session, however, gathering all the data required to calculate the dual task total score (transfer, rule and dropped coin errors, along with attending to alphabet recitation) places too large a burden on the evaluating clinician during the single session. All that data can only be acquired by recording the assessment for later analysis. This time commitment limits the user friendliness of this assessment and may prohibit use in a clinical setting. An alternative would be to use a completion time measure alone. However, as mentioned earlier, using total time as an outcome measure negates the importance of the errors made and does not allow for proper cost analysis. Further analysis of the C3t outcome variable and possible development of a new option is advisable.

Another limitation is the complexity of the C3t dual task condition. The attentional demands required for the motor manipulation of the coins, attending to the coin values for trial order, along with recitation of every other letter of the alphabet is too great; as noted by the high total cost levels and the mutual interference noted by most participants regardless of disability level. Further development of this condition must include evaluation of different combinations of cognitive/motor task complexity to find a condition that is challenging yet manageable and will differentiate individuals across levels of impairment.

In hindsight, some limitations/oversights that may have enhanced the study would have been to include repeat TUG testing in Session 2, and bring the HC back for Session 2 along with the PwPD, allowing C3t test re-test reliability for the HC in conjunction with dual task TUG test-re-test reliability for all participants. Insight may also have been gained from movement component analysis of the complex condition to identify if simply requiring the coin transport in order of descending value added enough task complexity to affect the movement components.
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Parkinson’s Disease Overview

Parkinson’s Major Cognitive and Motor Problems Leading to Dual Task

In additional to degradation of dopamine producing neurons in the substantia nigra, another diagnostic marker for PD is the presence of a mis-folded protein called Lewy Bodies. Alpha (α)-synuclein is the most prevalent protein in the Lewy body structure (Obeso et al., 2017). Individuals with PD gradually develop non-motor along with motor symptoms in the early and middle stages of the disease. With disease progression, all symptoms worsen causing functional decline and affecting an individual’s participation and quality of life (QOL) (Luquin, Kulisevsky, Martinez-Martin, Mir, & Tolosa, 2017).

There is currently no cure for PD but there are medical and therapeutic interventions designed to reduce physiological symptoms. Medical treatment most commonly involves medication engineered to replace depleted dopamine within the CNS, thus reducing the display of symptoms (Rascol, Payoux, Ferreira, & Brefel-Courbon, 2002). This pharmacologic intervention is very successful in the early stages of the disease when dopaminergic signs and symptoms are most prevalent and long-term complications have not yet developed. However, longstanding use of these medications can lead to other motor complications including motor fluctuation, dystonia, dyskinesia and end dose failure (Hely, Morris, Reid, & Trafficante, 2005). As a result, symptomatic medications are avoided, and are initiated only if patient and doctor agree that the severity of functional disability warrants drug intervention (Magrinelli et al., 2016; Rascol et al., 2002). Current medical management, primarily designed to replace lost dopamine, is more effective addressing the motor than the cognitive symptoms. Even with pharmacological intervention, individuals with PD still experience impairments of body function, inactivity, participation restriction,
increased dependence and social isolation, resulting in a decreased quality of life (Tomlinson et al. 2012). The limitations of pharmacological interventions have led to increased reliance on rehabilitation therapies, including physical therapy (PT). The role of PT is to maximize functional ability and minimize secondary complications through movement rehabilitation, education and support for the whole person (Tomlinson et al. 2012).

**Cognitive Impairments in Parkinson’s Disease**

**Executive Function**

Of the neuropsychiatric issues that are seen in PD, deficits in executive function (EF) abilities have the greatest potential to impact motor function and dual task ability. Executive function (EF) involves cognitive processes that are responsible for the accomplishment of goal-directed behaviors from inception to successful execution (Dirnberger & Jahanshahi, 2013). Definitions of EF are varied and classified according to different topical schemes. Lezak (1995) discussed four components of EF: volition, planning, purposeful action and effective strategies. Proposed domains of EF have become more focused and suggested areas include working memory deficits, planning, set shifting, inhibitory control, attention and conflict resolution (Cameron et al., 2010; Cools, Barker, Sahakian, & Robbins, 2001; Dirnberger & Jahanshahi, 2013; Kehagia, Barker, & Robbins, 2013; Lezak, 1995; Tinaz, Lauro, Hallett, & Horovitz, 2016).
Table A.1. An overview of the common executive function impairments seen in PD and common assessment measures that target these specific functions. Individual Test References see Appendix B.

<table>
<thead>
<tr>
<th>Executive Function</th>
<th>Description</th>
<th>Assessment</th>
</tr>
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</table>
| Working Memory     | Refers to the memory process of temporarily storing information in one’s mind and manipulating it over a short period. | • Digit Span Backwards  
• N-Back  
• Spatial Span Test  
(visuospatial working memory) |
| Planning           | The ability to identify and organize the steps and elements needed to formulate and carry out an intention and achieve a goal. Involves the conceptual activity, impulse control and sustained attention. | • CANTAB – Tower of London Test  
• Clock Drawing |
| Set Shifting       | The ability to switch rapidly between different response sets | • Wisconsin Card Sorting Test (WCST)  
• ID/ED Shift Test  
• Trail Making Test |
| Inhibitory Control | The ability to suppress an automatic response. Requires conscious supervision by the central executive and inhibition of a prepotent habitual response | • Stop Signal Task  
• Stroop Test  
• Hayling Sentence Completion |
| Attention          | The ability to selectively focus on a particular aspect of one’s environment, while ignoring competing stimuli | • TUG – COG  
• Stroop Test |
| Decision Making    | The ability to choose between two or more alternative behaviors that need consideration among available options according to the potential outcomes, the motivating drive and the goals of the individual. | • Cambridge Gambling Task (CGT)  
• Symbol Digit Modalities Test |

EF includes one’s ability to attend to their environment, absorb appropriate task-related information, manipulate that information in working memory, inhibit unnecessary information, organize and plan for a goal related action, and execute that
plan while accounting for unexpected shifts along the way. Deficits in executive function are at thought to include subcortical and cortical dysfunction (Pagonabarraga et al., 2008), due to degeneration of fronto-striatal “loops” (Alexander, DeLong, & Strick, 1986), or “circuits” (Magrinelli et al., 2016). In addition to dopaminergic degeneration, the other neural substrates thought to contribute to cognitive impairments are increased limbic and/or cortical Lewy body degeneration, subcortical pathology, synaptic pathology and neurotransmitter deficits, mitochondrial activity and/or neuro-inflammation (Aarsland et al., 2017). Decreases in dopamine cannot account for all cognitive deficits, as noted by the fact that these cognitive symptoms are not always improved with dopamine replacement treatment. Non-dopaminergic transmitter systems are believed to impact cognition including loss of cholinergic and noradrenergic pathways (Emre, 2007).

Following a series of studies examining the effects of neurotransmitters on EF in PwPD, Kehagia, et al (2013) describe a “dual- syndrome hypothesis” suggesting first, that EF deficits related to planning and working memory are related to dysfunction in dopamine and secondly, that other components of EF such as those involving fluctuating attention, appear to be unrelated to dopamine deficit. These deficits unrelated to dopamine degradation are not affected by dopamine replacement medication but instead are thought to reflect cholinergic dysfunction (Kehagia, Barker, & Robbins, 2010; Kehagia et al., 2013). All aspects of executive functioning have a potential impact on an individual’s daily functioning including their ability to dual task.

Motor Impairments in Parkinson’s Disease

Cardinal Signs and Functional Subsystems

The cardinal signs of PD (bradykinesia, rigidity and tremor) result from degeneration of nigrostriatal dopaminergic neurons and subsequent impairment to nigrostriatal pathways (Bellucci et al., 2016). Additionally, there is an accumulation
of α-synuclein protein Lewy bodies in the remaining neurons (Aarsland et al., 2017; Bologna et al., 2016; Khan et al. 2017). The cardinal signs of tremor, rigidity and bradykinesia affect other functional subsystems, most specifically postural control, gait and grasp and manipulation. Postural instability is well documented in individuals with PD and results in frequent episodes of falling. All PD patients eventually get postural instability but the balance control mechanisms may be different and vary from the early to later stages of the disease (Park, Kang, & Horak, 2015). Postural instability appears to be the impacted by multiple impairments. In the early stages of the disease, bradykinesia of postural responses and anticipatory postural adjustments may be the primary balance factors (Carpenter, Allum, Honegger, Adkin, & Bloem, 2004; Horak, Frank, Nutt, & Dow, 1996). With disease progression, impaired proprioceptive and kinesthetic input may compound the bradykinesia creating greater balance deficit (Konczak et al., 2009; Park et al., 2015). In the mid to later stages rigidity resulting in a flexed postural alignment and forward head affects overall biomechanics and resultant postural responses (Jacobs, Dimitrova, Nutt, & Horak, 2005). On a higher level, the basal ganglia play a large role in scaling the magnitude of postural movements, choosing postural strategies for environmental specifications and the automatization of postural responses (Jacobs et al., 2005; Takakusaki, Habaguchi, Ohtinata-Sugimoto, Saitoh, & Sakamoto, 2003).

**Motor Impairments in Individuals with Parkinson’s Disease**

As the disease progresses, in conjunction with the cardinal symptoms of PD, individuals with PD demonstrate motor deficits during both lower extremity and upper extremity movements. Gait disturbance is a common problem for persons with PD. Typically, patients present with a short step and stride length, shuffling of feet with decreased foot clearance. During gait, these steps become increasingly rapid, known as festination (Moustafa et al., 2016). Individuals with PD have difficulty initiating and terminating motion when walking and show difficulty with turning and transitions from one environment to another. Freezing during gait, a form of akinesia,
is common among patients with PD but the phenomenon is not universal. Freezing most commonly affects the lower extremities but arms and eyelids can also be involved (Jankovic, 2008).

This paucity of motion is also observed in areas of micrographia and fine motor coordination. Micrographia, a diminutive form of handwriting, presents early in the progression of PD. While performing handwriting, individuals with PD were found to exhibit increased movement time, reduced maximum and minimum values of magnitude of pen velocity and more velocity inversion (Tucha et al., 2006). The neural basis of impaired hand function have been explored by several groups, and may in part be related to the contribution of basal ganglia in monitoring sensory feedback. In a study looking at object grasp and lift PwPD were slow to initiate grip and had prolonged transition between various phases of the grip/lift movement (Ingvarsson et al., 1997). In addition to impairments in grip force modulation, studies have demonstrated impairments in individual finger movement and fine motor coordination. Delays were found between first digit contact with the object and lift initiation. Further, delays in movement initiation were related to disease stage (Ingvarsson et al., 1997). In a study examining coordination of fingertip forces during object grasp and release, PwPD performed similar to control subjects when moving at their preferred speed. When moving “as fast as possible”, PwPD employed a greater grip force than controls when statically holding the object in the air and demonstrated longer duration of isometric force decrease during object replacement. PwPD on medication also demonstrated a longer release time than healthy controls. (Gordon, 1998).

Individuals with PD also demonstrate deficits with bimanual coordination. Multiple studies have shown that individuals with Parkinson’s disease have greater difficulty than controls with bi-manual activities that involve bilateral upper extremities (BUE) moving out of phase (moving in different patterns) from one another. Greater deficits are seen with increasing speeds during such tasks (Almeida et al., 2002; Byblow et al., 2002; Ponsen et al., 2006). PD patients off medication
have been shown to demonstrate impairments in coordination of reach and grasp movement, specifically reduced coordination hand aperture and speed (Ingvarsson et al., 1997; Santello, Muratori, & Gordon, 2004) Interestingly, although dopamine replacement therapy (DRT) does ameliorate the majority of motor symptoms associated with PD, replacement of dopamine does not improve all symptoms.

Dual Task

Dual Task Background

Throughout an average day, it is uncommon for people to do one thing at a time. In our busy lives, people are always trying to get as much done as possible and this often involves performing activities simultaneously, such as walking while holding a conversation or sending a text or walking while carrying a drink or a diner plate or drinking coffee while driving a car. Concurrently performing two tasks at one time is called dual tasking. McIsaac et al. (2015) operationally defined dual task as “the concurrent performance of two tasks that can be performed independently, measured separately, and have distinct goals.” When an individual performs a dual task, the attention normally given to the execution of each single task must now be shared between the two. Typically, dual tasking is more challenging than performance of a single task alone and leads to a performance decrement in either one or both of the tasks. To determine the effect of one task on another, comparisons can be made between the performance during single-task and dual task conditions. If performance declines on one or both tasks when performed together, then the two tasks interfere with each other. This effect is called dual task interference (DTI) or dual task effect (DTE) (Plummer & Eskes, 2015). For the purposes of this review, this terminology will be used interchangeably. The change in outcome from the performance of the single task, to the performance of the same task under dual task conditions is considered to be the cost or benefit of doing the tasks simultaneously. Dual task cost (DTC) occurs when the outcome declines from single to dual task conditions whereas
dual task benefit (DTB) would indicate an improvement in performance outcome under the dual task compared to the single task conditions (McIsaac et al., 2015; Plummer & Eskes, 2015).

Individual tasks require use cognitive resources for their execution. The level of attentional resources required for any given task can depend on the complexity of the task and the novelty of the task to the performer (Magill & Anderson, 2017; McIsaac et al., 2015). If single task execution utilizes a certain level of attentional resource, then doing two things at once requires an increased cognitive load. Thus, dual task interference can occur when there is competition for limited attentional resources. Despite the complexity of the healthy human brain, it has limitations in its ability to process information (Marois & Ivanoff, 2005). There are multiple theoretical frameworks proposed to explain dual task interference, although two are most commonly discussed in the literature: the capacity sharing model (Tombu & Jolicœur, 2003) and the bottleneck theory (Pashler, 1994). The capacity sharing model suggests that people have some control over the allocation of their cognitive resources. Thus the information-processing required for performance of a dual task is a “flexible but limited resource” (Kelly et al., 2012; Pashler, 1994). Executing any single task requires a component of this resource. Performance of dual tasks require that cognitive resources such as attention be allocated between the two tasks. Each individual will choose to allocate their available resources differently based upon their individual resources, inherent preferences and their familiarity with the task, and the task specifics. The way each individual chooses to allocate their personal resources will impact the DTI seen during performance (Kelly et al., 2012; Meyer et al., 1997; Pashler, 1994).

The second theory proposed here to explain DTI is the bottleneck theory. This theory proposes serial processing of two concurrent tasks. DTI ensues when each of the dual tasks compete for the same processing resources. When two tasks need the same resources simultaneously, one task will proceed while the secondary task will be placed on hold. A bottleneck occurs and impaired performance may result in one or
both tasks (Kelly et al., 2012; Pashler, 1994; Ruthruff, Pashler, & Klaassen, 2001). Pashler (1994) proposes that there could be the possibility of single or multiple bottlenecks associated with various mental operations occurring at different phases of task execution. Processing limitations arising as the result of either of the above theories will impair dual task performance in healthy individuals. Limitations in individuals with an impaired central nervous system (CNS), such as neurodegenerative diseases, have the potential for greater DTI than is seen with a healthy CNS.

**Dual Task: Issues of Prioritization**

Jansen et al. (2016) is one of the few researchers to investigate dual task performance using a seated task; the majority of dual task studies emphasize upright activities involving balance and walking coupled with a secondary motor or cognitive task. In general, dual task study results are difficult to compare due to methodological differences, along with differences in subject characteristics, task complexity, coupling of cognitive-motor or motor-motor tasks and varying environmental constraints (Kelly et al., 2012; Plummer, Apple, Dowd, & Keith, 2015; Ruffieux, Keller, Lauber, & Taube, 2015). A study examining dual task priority for young adults texting while walking in both laboratory and real-world environments found subjects prioritized texting in the lab setting, but gave equal priority to texting and walking in the busier, real-world setting (Plummer et al., 2015). These findings give credence to the “safety-first” theory, as less attention was required for walking in the quiet laboratory environment. However, in the busier, real-world situation, subjects looked up from their phone more frequently to avoid collision with others. Another study found healthy young adults shifted dual task priority toward the walking task and away from the secondary task as the tasks became more challenging, again appearing to prioritize safety (Kelly, Janke, & Shumway-Cook, 2010). This “posture-first” strategy may not be employed as consistently as adults grow older.
Bloem et al. developed a sequential series of eight tasks with increasing complexity across tasks called “The Multiple Tasks Test” (Bloem et al., 2001). The tasks were designed to simulate common everyday activities and performance outcomes were compared between young and elderly participants. The elderly participants consistently made more motor errors than cognitive errors during the more complex tasks, indicating they prioritized the cognitive component. However, the younger participants prioritized the motor component of the complex tasks over the cognitive, speeding through the tasks with a noted decline in cognitive performance. This led Bloem et al. to suggest the elderly subjects were not prioritizing a “posture-first” strategy (Shumway-Cook et al., 1997) and were instead sacrificing safety (Bloem et al., 2001).

The majority of information regarding DT prioritization comes from studies evaluating upright activities where postural control is a critical task component, while dual task control under seated conditions is not well understood (McIsaac & Benjapalakorn, 2015). To address this limitation, McIsaac and Bejapalakorn developed a seated driving simulation activity to assess DT interference/prioritization during a motor-motor dual task involving upper and lower limb coordination under two different task conditions. They found prioritization to differ according to task conditions, thus their participants prioritized the upper extremity task over the foot pedal for the “gradual ramp” condition, but equal priority was given to upper and lower extremity tasks during the “steep ramp” condition. In this study, the shape/challenge of the ramp affected prioritization choice. The investigators proposed that attention was “flexibly allocated and tasks prioritized based on the structure of the tasks” (McIsaac & Benjapalakorn, 2015). Therefore, it is evident from the studies discussed above, that individual prioritization of simultaneously-performed tasks can be based on performer resources (i.e., age), task environment (i.e., closed or open) and/or task complexity (i.e., steep ramp vs gradual ramp). Prioritization of tasks may also be different when coupled with a postural task such as standing or walking compared to a seated task where upper extremities are “uncoupled from posture and
balance concerns” (McIsaac & Benjapalakorn, 2015). Further research is needed to determine how task prioritization may differ during upright and seated conditions.

**Dual Task Performance with Aging**

If one determinate of task prioritization is one’s personal resources then the multiple changes in cognitive and motor function observed as a part of normal aging and further impaired with development of PD may make dual tasking even more challenging. Aging decline in motor performance can be related to physiologic change to muscle or to age-related decline of various neural networks underlying function (Ward & Frackowiak, 2003). The individual changes in motor and cognitive function may develop gradually and result in small compensations needed for aging adults to maintain independence with functional daily activities. Increasing task complexity or dual task situations further challenge an aging system resulting in decreased performance on many dual tasks with aging. Many studies have researched dual task ability in older adults and most indicate performance decrements for older adults compared to young although results indicate conflicting pattern of decline (Brustio, Magistro, Zecca, Rabaglietti, & Liubicich, 2017; Hahn, Wild-Wall, & Falkenstein, 2011; Maclean, Brown, Khadra, & Astell, 2017; Porciuncula, Rao, & McIsaac, 2016; Ruffieux et al., 2015; Vaportzis, Georgiou-Karistianis, & Stout, 2013, 2014). The largest body of research looking at dual task and aging focus on primarily upright tasks involving standing and walking performed with the addition of a secondary task. Four studies evaluated upper extremity function under dual task conditions with an aging population. Generalized conclusions indicate that: a) performance declined from single to dual task condition, and this progressively increased with age; b) movement tasks were was slowed and more variable when performed under dual-task conditions compared to single task and c) difficult tasks had a greater effect on dual task performance in the elderly, suggesting a decrease in attentional resources with aging (Crossley & Hiscock, 1992; Van Impe, Coxon, Goble, Wenderoth, & Swinnen, 2011; Vaportzis et al., 2013, 2014). All of the above
studies looked at motor cost as the result of cognitive interference without examining the cognitive cost, thus nothing could be gleaned about task prioritization during these studies.

Upright studies examining standing or walking along with dual tasks have examined task-prioritization with aging. Some studies support that older adults prioritizing a posture-first strategy (Hahn et al., 2011; Maclean et al., 2017; Schaefer & Schumacher, 2011), while others challenge this idea indicating a “posture-second” strategy (Agmon, Kodesh, & Kizony, 2014; Brustio et al., 2017; Schaefer, Schellenbach, Lindenberger, & Woollacott, 2015). In a review of studies looking at the effect of dual task on postural control, it was suggested that both young and older adults are able to maintain their postural control while performing a sequential task under stable conditions. However, when task complexity increases (dynamic conditions such as an unstable surface or surround) single and/or dual task performance declines for the older adults compared to the younger participants. The most significant impact was the result of a dynamic surface, which would provide inaccurate sensory input to the postural control system. (Boisgontier et al., 2013). These authors concluded that older adults rely heavily on sensory input for postural control. Additionally, postural control in older adults becomes less automatic requiring increased attentional resources, thus impacting the dual task performance (Boisgontier et al., 2013).

Again, many of the studies reviewed examined the effect of a cognitive task on motor performance but did not consider the effect of the motor task on the cognitive performance. Brustio et al. considered the DTC of both cognitive and motor tasks, finding that all three of their age groups demonstrated an effect of the cognitive task on the motor task, with larger mobility declines with aging. They also found mutual interference in all groups, indicating that the combination of motor and cognitive tasks together, also influenced the cognitive task performance (Brustio et al., 2017). As with the UE studies, increasing task complexity in the upright studies resulted in greater decrement in motor performance for the older adults, indicating that they were
not prioritizing their posture over the cognitive task. Older adults may waste attentional resources by allocating them to irrelevant features of the task and not attending to the most relevant stimuli. This allocation of attentional resources away from the motor to the cognitive task could impair safety during complex task situations (Brustio et al., 2017). It remains unclear whether older adults regularly choose to prioritize posture or a secondary task when dual tasking under complex conditions. What is clear, is that younger and older adult may choose different behavioral strategies when performing dual tasks and these strategies may vary depending on task novelty and complexity (Vaportzis, Georgiou-Karistianis, Churchyard, & Stout, 2015). Additionally, performing two tasks at once is more challenging for older adults than performing a single task alone. In light of this information, using dual task assessment to identify motor and cognitive decline in aging individuals may produce more insights into cognitive and functional decline than single task analysis alone (Maclean et al., 2017).

**Dual Task Ability in Individuals with Parkinson’s Disease**

Individuals with PD are experiencing the changes noted with normal aging coupled with the degeneration of multiple brain structures, impacting both motor and cognitive function. Multiple factors many impact DT performance including but not limited to impaired motor capabilities, executive function, depression, fatigue, impaired balance, fear of falling, disease severity and medication. (Rochester et al., 2004, 2008). Overall, studies show that PwPD show an increase in cognitive-motor interference when comparing dual task to single task performance and a decline in most conditions when compared to healthy age-matched controls (Wild et al., 2013). Dual task difficulty increases with secondary task complexity (Bloem et al., 2006b). “Posture-first” is not a consistently chosen prioritization strategy. Whereas elderly individuals may tend to give equal priority to both motor and cognitive tasks in a complex situation, PwPD often demonstrate a “posture-second” strategy prioritizing the cognitive task over the upright motor task (Bloem et al., 2006b). Some
Parkinson’s specific issues may influence PD individuals’ ability to dual task while walking include decreased movement automaticity, dopamine-mediated dysfunction and non-dopaminergic pathology.

Greater movement difficulty seen with neurodegenerative diseases, may indicate decreased automaticity (Fritz et al., 2015). Automaticity, first described by Posner (1978) means the ability to perform a task without “attentional executive control.” Learning a new movement skill can occur in 3 stages: cognitive, associative and autonomous (Fitts & Posner, 1967). In the later autonomous stage of learning, performance of a movement or skill can be described as “almost automatic or habitual” (Magill & Anderson, 2017). It is during this late stage in the skill acquisition process when a movement task can be executed without attentional executive control required, leaving our cognitive resources to be allocated to other accomplishments. In the case of Parkinson’s disease, people gradually lose the ability to automatically execute well-learned movements (Strouwen, Molenaar, Keus, Münks, Heremans, et al., 2016). This decreased automaticity of previously automatic motor tasks now requires attentional resources be allocated to motor performance leaving greater resource restriction for dual task performance. This decreased automaticity may be one, if not the primary reason those with PD demonstrate greater dual task difficulty than healthy elderly individuals (Fritz et al., 2015; Rochester et al., 2004).

One possible issue is the reduced movement automaticity described above. The basal ganglia is proposed to play a role in movement automaticity, thus basal ganglia dysfunction seen with PD may necessitate increased cognitive resources directed toward movement control (Beck & Almeida, 2017; Kaoru Takakusaki, Oohinata-Sugimoto, Saitoh, & Habaguchi, 2004). PwPD demonstrate extensive changes in movement automaticity as evidenced by an ability to alter movement (i.e., take a larger step) as the result of externally provided cue (i.e., lines on a floor or the beat of a metronome) but an inability to cue themselves for production of the same movement. This significant decrease in movement automaticity required attentional
resource allocation to the walking and away from the secondary task (Kelly et al., 2012). As with the aging population, this increased requirement for attention allocation to daily movement, may result in falling or injury when attention is diverted away from movement by execution of a secondary task. Decreased automaticity in combination with an executive function decline can have great impact on dual task abilities.

A second possibility is “dopamine-mediated dysfunction” (Kelly et al., 2012). The basal ganglia is thought to contribute to multiple functional loops/circuits involving different neuroanatomical structures and affecting multiple systems. Magrinelli et al. (2016) discusses a motor circuit, an oculomotor circuit, an associative (or cognitive) circuit and a limbic circuit. Parkinsonian degeneration of dopamine producing cells affects both cognitive and motor function and influencing dual task walking function, which is partially improved by anti-Parkinson’s medication. This mitigated improvement supports the idea that dopamine depletion impacts DT function in PD (Kelly et al., 2012). A third suggestion is that non-dopaminergic pathology is also present in PD which may have an effect on DT walking performance (O ‘Shea, Morris, & Iansek, 2002). This might explain why dopamine replacement medication does not correct all DT deficits. There is no one solution to explain the variety of outcomes seen in Parkinson’s dual task studies whether focusing on upper extremity or lower extremity tasks.

**Dual Task with Parkinson’s Disease: Focus on Lower Extremity (LE Tasks)**

Fuller et al. (2013), examined whether DT performance in PD could be a predictor of impairment or disability in this population. Considering verbal fluency and walking tasks under both single and dual task conditions, the researchers found that under DT conditions, PwPD demonstrate mutual interference on both cognitive and motor tasks when compared to single task performance. Regression analysis indicated that the proportional change in verbal fluency between single and dual task conditions was a predictor of disability. This predictive pattern was seen only for
verbal fluency and not for walking. Although some methodological limitations may have had an impact on the outcomes, these finding may provide credence to the idea that cognitive deficits are seen earlier in the disease development than motor symptoms and that a dual task assessment may be more sensitive in detecting these early manifestations than single modality assessment alone.

O’Shea et al. examined walking in PwPD and healthy controls under single task conditions at a self-selected pace, in combination with either a secondary motor or cognitive task. During single task conditions, they found mean stride length and gait speed to be decreased in PwPD compared to controls. Under dual task conditions, both groups demonstrated a decreased stride length and gait speed but the PD group also demonstrated a decreased mean cadence with DT. Whether the secondary task was a motor vs cognitive secondary task had very little effect on DT performance for either group (O’Shea et al., 2002). In this study, as in many, researchers examined the motor DTC imposed by the cognitive task but did not address the cognitive DTC imposed by the motor task, thus giving only half of the cognitive/motor interference picture.

In a recent study Strouwen et al. (2016), looked at both motor and cognitive DTC during a walking task. Both PD and control groups walked under single and multiple DT conditions to determine if the nature of the DT influenced performance in any way. Secondary tasks included backwards digit span, an auditory Stroop task, and a mobile phone typing task. They found single task gait velocity to be the primary predictor of dual task gait velocity indicating that motor impairment was the contributing factor to DT deficit. Results showed gait outcomes to be similarly irrespective of secondary task type. They also noted that PwPD seemed to prioritize all types of secondary task at the expense of gait – supporting the “posture-second” strategy. Thus, considering these walking studies along with the prioritization studies discussed earlier, prevalent concepts appear to be that PwPD demonstrate impairment when compared to healthy age-matched controls and in task performance when comparing single and dual task conditions. The type of secondary task does not seem
to have a significant impact on walking performance. PwPD internally prioritize one task over another, however their choice may not always be in the interest of safety. If instructed to do so, individuals are capable of shifting their inherent DT priority to from one task to another, but the request may be ignored. Existing studies however have too many variations in methodology, subject characteristics, task demands and environmental difference for concrete comparison or conclusions.

**Dual Task with Parkinson’s Disease: Focus on Upper Extremity (UE) Tasks**

Unlike the many upright studies addressing DT performance in PwPD, very few dual task studies done in PwPD have looked at UE tasks. Teixeira and Alouche (2007), compared performance of PwPD and controls buttoning a seven-button shirt, both as a single task and in conjunction with a secondary cognitive task. Groups had 3 trials under each condition. Results demonstrated that the PwPD were slower buttoning the seven buttons, with more errors than controls in both conditions. The researchers did not address the cognitive task performance outcomes. All subjects presented with significantly faster buttoning times on trials 2 and 3 for each task, indicating a learning effect.

Proud and Morris (2010), examined the effects of adding a concurrent task to the assessment of skilled hand dexterity. PwPD and age-matched controls completed the Purdue Pegboard Test as a single task and as a dual task while performing serial 7 subtractions. The tests were performed on both dominant and non-dominant hands. No differences were found between control and PD groups when performing serial 7s subtraction as a single task. Differences were found between groups when performing the peg board as a single task. PwPD placed significantly fewer pegs using both the dominant and non-dominant hands. When performing the two tasks simultaneously, both groups demonstrated a reduction in number of pegs placed/session, however PwPD demonstrated a greater cognitive DTC than controls with decreased cognitive performance, while motor performance remained consistent.
Pradhan, Sujata, Bambi, Carvell, & Sparto (2010), developed assessment tool to quantify fine-motor deficits in PwPD, using a grip instrument to measure pinch between thumb and index finger. Experimental and control subjects were asked to generate a pinch force, producing a visual on a computer screen. Subjects were asked to use this visual image to track target waveforms presented on the screen. Subjects performed sinusoidal tracking and random tracking tasks. Each tracking task was performed under three conditions: 1. No cognitive load, 2. Serial 1s subtraction and 3. Serial 3s subtraction. PwPD performed both tracking tasks poorly compared to control subjects under single task conditions. Performance declined consistently as the serial task cognitive load increased.

The final DT UE study for individuals with PD returned to the Purdue Pegboard used in the Proud and Morris study (2010). PwPD completed the pegboard task under 3 conditions. 1. Single task, 2. A squeezing ball activity was performed in one hand while the other hand completed the pegboard task, 3. Performing a “verbal-cognitive task based on a questionnaire” along with the pegboard task. No control group was included. Results show that both motor/motor and motor/cognitive tasks interfered with hand dexterity in PwPD, but greater DTI was noted with the motor/cognitive task than the motor/motor task. Researchers reported this interference was consistent across individuals at stage I, II and III H&Y. The cognitive task was not explained and the outcomes of the secondary tasks were not reported, thus it is difficult to get a full understanding of the interference (Kalirathinam & Vaidya, 2014). Although there has been increased awareness to cognitive-motor interference for PwPD in the literature, the majority of studies have focused on balance with little focus on upper extremity movements during dual task activities. Understanding the differences in dual task performance and prioritization between an upright, lower extremity tasks with substantial postural control needs and a seated, upper extremity dual task activities may allow us to better understanding of disease specific deficits. Improved understanding of such deficits may allow early disease detection and improved intervention strategies.
# Appendix B

## Assessment References

<table>
<thead>
<tr>
<th>Executive Function</th>
<th>Assessment</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Working Memory</td>
<td>Digit Span Backwards</td>
<td>(Warden, Hwang, Marshall, Fenesy, &amp; Poston, 2016)</td>
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<tr>
<td></td>
<td>N-Back</td>
<td>(Kane, Conway, Miura, &amp; Colflesh, 2007)</td>
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<tr>
<td></td>
<td>Spatial Span Test</td>
<td>(Orsini et al., 1987)</td>
</tr>
<tr>
<td>Planning</td>
<td>CANTAB – Tower of London Test</td>
<td>(Fray, Robbins, &amp; Sahakian, 1996)</td>
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<td></td>
<td>Clock Drawing</td>
<td>(Manos &amp; Wu, 1994)</td>
</tr>
<tr>
<td>Set Shifting</td>
<td>Wisconsin Card Sorting Test (WCST)</td>
<td>(Anderson SW et al., 1991)</td>
</tr>
<tr>
<td></td>
<td>ID/ED Shift Test</td>
<td>(Downes et al., 1989)</td>
</tr>
<tr>
<td></td>
<td>Trail Making Test</td>
<td>(Arbuthnott &amp; Frank, 2000)</td>
</tr>
<tr>
<td>Inhibitory Control</td>
<td>Stop Signal Task</td>
<td>(Lipszyc &amp; Schachar, 2010)</td>
</tr>
<tr>
<td></td>
<td>Stroop Test</td>
<td>(Stroop, 1992)</td>
</tr>
<tr>
<td></td>
<td>Hayling Sentence Completion</td>
<td>(Burgess &amp; Shallice, 1996)</td>
</tr>
<tr>
<td>Attention</td>
<td>TUG – COG</td>
<td>(C. M. Campbell et al., 2003)</td>
</tr>
<tr>
<td></td>
<td>Stroop Test</td>
<td>(Stroop, 1992)</td>
</tr>
<tr>
<td>Decision Making</td>
<td>Cambridge Gambling Task (CGT)</td>
<td>(Rogers et al., 1999)</td>
</tr>
<tr>
<td></td>
<td>Symbol Digit Modalities Test</td>
<td>(Sheridan et al., 2006)</td>
</tr>
</tbody>
</table>
Appendix C

IRB Approval Letters

1. Teachers College original IRB approval letter – 7/18/2018

To: Julie Fineman
From: Karen Froud, IRB Chair
Subject: IRB Approval: 18-427 Protocol
Date: 07/18/2018

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has given full approval to your study, entitled "Measuring Functional Dexterity and Dual-Task Ability in Individuals with Parkinson's Disease as Compared to Healthy Peers," after a Full Board Review.

The approval is effective until 07/17/2019.

The IRB Committee must be contacted if there are any changes to the protocol during this period. Please note: If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by 06/12/2019 so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is 18-427. Feel free to contact the IRB Office (212-678-4105 or IRB@tc.edu) if you have any questions.

Please note that your Consent form bears an official IRB authorization stamp. Copies of this form with the IRB stamp must be used for your research work. Further, all research recruitment materials, including online announcements, e-mails, hard-copy flyers, etc., must include the study's IRB-approved protocol number.

Best wishes for your research work. Sincerely,

Karen Froud, Ph.D.
Associate Professor of Neuroscience & Education IRB Chair
2. Teachers College IRB approval renewal letter – 6/19/19

To: Julie Fineman  
From: Karen Froud, IRB Chair  
Subject: IRB Approval: 18-427 Protocol  
Date: 06/19/2019

Please be informed that as of the date of this letter, the Institutional Review Board for the Protection of Human Subjects at Teachers College, Columbia University has approved your continuing study, entitled "Measuring Functional Dexterity and Dual-Task Ability in Individuals with Parkinson's Disease as Compared to Healthy Peers" on 06/19/2019.

The approval is effective until 07/17/2020.

The IRB Committee must be contacted if there are any changes to the protocol during this period. Please note: If you are planning to continue your study, a Continuing Review report must be submitted to either close the protocol or request permission to continue for another year. Please submit your report by 06/12/2020 so that the IRB has time to review and approve your report if you wish to continue your study. The IRB number assigned to your protocol is 18-427. Feel free to contact the IRB Office (212-678-4105 or IRB@tc.edu) if you have any questions.

As subject enrollment is complete, no newly stamped copy of the consent form is provided with this continuing approval. You may retrieve a PDF copy of this approval notification from the Mentor site.  
As the PI of record for this protocol, you are required to: Use current, up-to-date IRB approved documents. Ensure all study staff and their CITI certifications are on record with the IRB Notify the IRB of any changes or modifications to your study procedures Alert the IRB of any adverse events

You are also required to respond if the IRB communicates with you directly about any aspect of your protocol. Failure to adhere to your responsibilities as a study PI can result in action by the IRB up to and including suspension of your approval and cessation of your research.

Best wishes for your research work. Sincerely,

Karen Froud, Ph.D.  
Associate Professor of Neuroscience & Education IRB Chair
MARIST COLLEGE INSTITUTIONAL REVIEW BOARD

MEMORANDUM

To: Julie Fineman, PT, EdM
Subject: IRB proposal # S18-0 28
Date: March 20, 2018

In accordance with federal regulations, the Marist College Institutional Review Board has been given the authority by President David Yellen to act on the above-referenced protocol.

After reviewing your protocol, the IRB has determined that it involves human subjects who will not be at risk and has given approval effective immediately.

This approval applies only to the above-referenced protocol. It is incumbent on you, furthermore, to secure prior approval of the Board for any changes in your proposed procedures that will affect your use of human subjects. You must also report to the Board any problems that arise in connection with your use of human subjects in this activity.

This approval is valid for ONE YEAR ONLY. You must request a continuation of the approval if the activity lasts more than one year.

If you question any of these determinations, you have the option of requesting a full review by the IRB which will make the final determination.

NOTE: The IRB may request a full review to reconsider any protocol approved under expedited review. You will be notified in advance of this review.

APPROVAL OF THIS PROTOCOL BY THE IRB ONLY SIGNIFIES THAT THE PROCEDURES ADEQUATELY PROTECT THE RIGHTS AND WELFARE OF THE SUBJECTS AND SHOULD NOT BE TAKEN TO INDICATE COLLEGE APPROVAL TO CONDUCT THIS RESEARCH.

Erik Moody, Ph.D. Chair, IRB
MARIST COLLEGE INSTITUTIONAL REVIEW BOARD

MEMORANDUM

To: Julie Fineman
Subject: IRB proposal # S18-028 Date: 03/12/2019

In accordance with federal regulations, the Marist College Institutional Review Board has been given the authority by President David Yellen to act on the above-referenced protocol.

After reviewing your protocol, the IRB has determined that it involves minimal risk to human subjects, and has given approval effective immediately.

This approval applies only to the above-referenced protocol. It is incumbent on you, furthermore, to secure prior approval of the Board for any changes in your proposed procedures that will affect your use of human subjects. You must also report to the Board any problems that arise in connection with your use of human subjects in this activity.

This approval is valid for ONE YEAR ONLY. You must request a continuation of the approval if the activity lasts more than one year.

If you question any of these determinations, you have the option of requesting a full review by the IRB which will make the final determination.

NOTE: The IRB may request a full review to reconsider any protocol approved under expedited review. You will be notified in advance of this review.

APPROVAL OF THIS PROTOCOL BY THE IRB ONLY SIGNIFIES THAT THE PROCEDURES ADEQUATELY PROTECT THE RIGHTS AND WELFARE OF THE SUBJECTS AND SHOULD NOT BE TAKEN TO INDICATE COLLEGE APPROVAL TO CONDUCT THIS RESEARCH.

Chair, IRB
Appendix D
Consent Forms

INFORMED CONSENT

Protocol Title: Measuring Functional Dexterity and Dual-Task Ability in Individuals with Parkinson's Disease as Compared to Healthy Peers

Principal Investigator: Julie Fineman, PT, EdM Teachers College, Columbia University, jbf11@tc.columbia.edu
Marist College, 845-575-4754, julie.fineman@marist.edu

INTRODUCTION
The reason for this form is to give you information to help you decide if you want to take part in this research study.

This consent and HIPAA authorization form includes information about:
- Why the study is being done;
- What is involved if you choose to be in the study;
- Any known risks involved;
- Any potential benefit;
- Options, other than taking part in this study, that you have; and the way your health information will be used and shared for research purposes.

The principal investigator (the lead researcher for this project) will discuss the study with you. If at any time you have questions about the study, please ask a study team member. Take all the time you need to decide whether you want to take part in this research study. This consent and the federal Health Information Portability and Accountability Act (HIPAA) authorization form are written to address a research subject. The purpose of this research is described below.

DESCRIPTION OF THE RESEARCH:
You are invited to participate in a research study aimed at looking at the effects of hand function and multi-tasking in people with Parkinson’s disease. You may qualify to take part in this research study because you are over 40 years old and are:
1) diagnosed with Parkinson’s disease or 2) a healthy adult. Approximately seventy-
five people will participate in this study. This study requires that you come to our research laboratory at Marist College on two occasions. Your participation will take a total of approximately 2 hours on the first day and approximately 15-20 minutes 1 week later on the second day.

Video and audio recording is part of this study. If you do not wish to be recorded you cannot participate in this study. Access to your health information is required to be part of this study. If you choose to take part in this study, you are giving us the authorization (i.e., your permission) to use the protected health information and information collected during the research that can identify you. The health information that we may collect and use for this research may include medical history that may be considered sensitive.

WHY IS THIS STUDY BEING DONE?
Often people with Parkinson’s disease have difficulty with tasks that require use of their hands for small activities like buttons, handwriting or holding small objects. Some physical therapy tests have been created to measure hand function in people with Parkinson’s disease.

Another possible problem in people with Parkinson’s disease is doing two things at the same time. Doing two things at once is called dual tasking. The purpose of this study is to evaluate a new test of hand mobility in people with Parkinson’s disease and to look at how people with Parkinson’s disease perform different types of activities together compared to a similar group of healthy people. We are interesting in looking at your hand ability on a variety of different tests. We are also interested in finding out how you will be able to divide your attention between different types of activities.

This study is a combined project between Teachers College, Department of Biobehavioral Sciences and Marist College, Doctor of Physical Therapy Program. This study partially fulfills the requirement for Ms. Fineman’s doctoral dissertation.

The principal investigator, Julie Fineman is a physical therapist and has years of experience evaluating and treating problems related to Parkinson’s disease. The two visits will be conducted with Ms. Fineman and will be held in our lab at Marist Doctor of Physical Therapy Program.

WHAT WILL I BE ASKED TO DO IF I AGREE TO TAKE PART IN THIS STUDY?
If you agree to be in this research study, you will be asked to come to our lab two times for an evaluation of your hand function and ability to perform dual tasks. We will request that you bring a copy of the note from your most recent Neurology visit, which will give us more information about your diagnosis and severity of your disease.

On your first visit we will: Ask you to complete a short survey gauging your memory and recall.
- Ask that you complete a survey reporting on the severity of your diagnosis.
- Take some measures of strength and will ask you some questions about your history and your functional abilities.
- Test your hand function by having you answer a few surveys and perform several hand function tests.
- Measure your ability to dual task by asking you to perform some activities seated at a table and some while standing and walking short distances. For one of the tests, we will place up to 2 small monitors on your wrists and one on your chest in order to measure your movements in detail.
- Ask you to complete timed surveys and tasks that assess your dexterity and hand function.
- That you complete a demographic survey (e.g., age, gender, etc.).

Participation on day one will involve a total of 3 paper assessments/questionnaires and nine different physical assessment in a lab setting requiring a total time of just under 2 hours (109 minutes) and an additional 20 minutes on day two (one week later). Some tasks require video and audio recording so we can look closely at your hand performance.

**WHAT POSSIBLE RISKS OR BENEFITS CAN I EXPECT FROM TAKING PART IN THIS STUDY?**

Every research study has some risk. Some tasks may be physically uncomfortable for you. Subjects may experience some discomfort with the “Pinch and Grip” test (or other such physical assessments). There is a potential risk of falling during the standing and walking components of this study. The risk of falling should be no greater than during your daily functional activities. We will take every precaution to ensure your safety. All of the screening procedures that you will undergo are part of standard clinical practice. They are designed to be safe and effective. The researcher who will complete these tests with you has years of experience working with people with Parkinson’s disease. Additionally, the risk to subjects has been minimized by the choice of non-invasive data collection procedures. Throughout the study, the researcher will ask you to gauge your physical comfort level for completing each task. All subjects will be allowed to take rest breaks, drink water, or stop the study whenever needed throughout each session. You can stop participating in any task, at any time, without penalty.

Some participants may be uncomfortable answering some questions on the questionnaires. Participants will have the option of omitting any questions, which will minimize this risk. A risk of taking part in this study is the possibility of a loss of confidentiality or privacy. Loss of privacy means having your personal information shared with someone who is not on the study team and was not supposed to see or know about your information. The study team plans to protect your privacy. Their plans for keeping your information private are described in the privacy section of this consent form.
There is no direct benefit to participating in this research study.

Participation in this study is voluntary. If you decide to participate now but change your mind later, there will be no penalties. In addition, while enrolled in the study, you may refuse to complete any test or questionnaire without penalty.

**WILL I BE PAID FOR BEING IN THIS STUDY?**
There will be no payment for your participation in this study.

**DATA STORAGE TO PROTECT CONFIDENTIALITY:**
Your privacy will be protected at all times. All of the data collected is considered confidential. Once you are enrolled in the study, you will be assigned a subject number. That subject number will have no ties to you and will allow for all data (both computer and survey data) to be stored in a masked manner. Only the principal investigator (PI) will have access to the sheet including subject name and number. All digital data including audio/video recordings will be masked and will be stored in a password protected, computer. All paper surveys will also be masked and will be stored in a locked file cabinet in the Principal Investigators’ office -#219 Allied-Health Building, Marist College. All study information including audio/video recordings will be kept for 5 years and then be shredded or deleted.

Any health information collected as part of this study will only be reviewed by authorized research staff and will be handled securely. All health information collected for this study will be kept for 5 years and then be shredded or deleted.

For quality assurance, the study team, the study sponsor (grant agency), and/or members of the Teachers College Institutional Review Board (IRB) or Marist College IRB may review the data collected from you as part of this study. Otherwise, all information obtained from your participation in this study will be held strictly confidential and will be disclosed only with your permission or as required by U.S. or State law.

**HOW WILL RESULTS BE USED:**
The results of the study will be used to advance the understanding of the effects of Parkinson’s disease on hand function and dual-task ability. In addition, this study information will be used as part of the primary investigator’s doctoral dissertation. The findings will be released through presentations at conferences and meetings, through talks with therapists and through a published dissertation and other journal publications. Any presentation or publication (e.g., at conferences, journal articles, etc.) that results from this study will only use de-identified data. Your name will never be used and your participation in this study will never be disclosed.
WHO CAN ANSWER MY QUESTIONS ABOUT THIS STUDY?
If you have any questions about taking part in this research study, you should contact the principal investigator, Julie Fineman (845) 575-4754 or Julie.fineman@marist.edu.

If you have questions or concerns about your rights as a research subject, you should contact the Institutional Review Board (IRB) (the human research ethics committee) at Marist 845.575.3000 x 2692, or email erik.moody@marist.edu. You can write to the Marist College IRB at 3399 North Road, 323 Dyson, Poughkeepsie, NY 12601. Additionally, you may contact Teachers College IRB at 212-678-4105 or email IRB@tc.edu. You can write to the IRB at Teachers College, Columbia University, 525 W. 120th Street, New York, NY 1002. The IRB is the committee that oversees human research protection for Teachers College, Columbia University.
PARTICIPANT’S RIGHTS

Protocol Title: Measuring Functional Dexterity and Dual-Task Ability in Individuals with Parkinson's Disease as Compared to Healthy Peers

Principal Investigator: Julie Fineman, PT, EdM Teachers College, Columbia University, jbf11@tc.columbia.edu
Marist College, 845-575-4754, julie.fineman@marist.edu

- I have read and discussed the informed consent with the researcher. I have had ample opportunity to ask questions about the purposes, procedures, risks and benefits regarding this research study.
- I understand that my participation is voluntary. I may refuse to participate or withdraw participation at any time without penalty.
- The researcher may withdraw me from the research at his or her professional discretion if I do not meet the criteria for participation or if I am unable to complete the required activities.
- If, during the course of the study, significant new information that has been developed becomes available which may relate to my willingness to continue my participation, the investigator will provide this information to me.
- Any information derived from the research study that personally identifies me will not be voluntarily released or disclosed without my separate consent, except as specifically required by law.
- Your data will not be used in further research studies.

CONSENT FOR AUDIO AND VIDEO RECORDING
Audio and video recording is part of this research study. You can choose whether to give permission to be recorded. If you decide that you don’t wish to be recorded, you will not be able to participate in this research study.

_____ I give my consent to be recorded _______ Signature

_____ I do not consent to be recorded _______
WHO MAY VIEW MY PARTICIPATION IN THIS STUDY

_____ I consent to allow written, video and/or audio recorded materials viewed at an educational setting or at a conference outside of Teachers College

Signature

_____ I do not consent to allow written, video and/or audio recorded materials viewed outside of Teachers College Columbia University

Signature

OPTIONAL CONSENT FOR FUTURE CONTACT
The investigator may wish to contact you in the future. In addition, if you agreed to participate in future research, you will be added to our Parkinson’s disease database, and may be contacted about participating in future Parkinson’s disease research.

Please indicate whether you give permission for future contact.

I give permission to be contacted in the future for research purposes:

Yes_____ No____
Initial Initial

HIPPA Agreement:
If you sign this document, you give permission to all doctors, all health care providers to use or disclose (release) your health information that identifies you for the research study described here in this consent form.

The health information that we may use or release for this research includes your medical records related to your diagnosis of Parkinson’s disease. The information to be used for this research study includes physical examinations, neurological examinations, test scores, and medication use, past and present.

The health information listed above may be used by and/or disclosed (released) to:

- Julie Fineman, PT. EdM
- Marist College Institutional Review Boards or Data Safety and Monitoring Boards
- Julie Fineman is required by law to protect your health information. By signing this document, you authorize Julie Fineman to use and/or disclose (release) your health information for this research. Those persons who receive your health information may not be required by Federal privacy laws (such as the Privacy Rule) to protect it and may share your information with others without your permission, if permitted by laws governing them.

Marist Institutional Review Board
Protocol # S18-028
Consent Form Approved Until 3/15/20
• You may change your mind and take back this authorization at any time, except to the extent that Julie Fineman has already acted based on this authorization.

• To withdraw your authorization, you must write to:

  Julie Fineman, PT, EdM
  julie.fineman@marist.edu
  or
  C/o Marist Doctor of Physical Therapy Program
  3399 North Road, Allied health Building #231
  Poughkeepsie, NY 12601

• This authorization will expire at the end of the research study.

STATEMENT OF CONSENT AND HIPAA AUTHORIZATION
I have read the consent and talked about this research study, including the purpose, procedures, risks, benefits, alternatives, and HIPPA authorization/form with the researcher. Any questions I had were answered to my satisfaction. I am aware that by signing below, I am agreeing to take part in this research study and that I can stop being in the study at any time. I am not waiving (giving up) any of my legal rights by signing this consent form. I will be given a copy of this consent with my HIPPA authorization form to keep for my records.

My signature means that I agree to participate in this study.

Participant's signature: _____ Date: /_____/_____

Printed Name: ______

INVESTIGATORS VERIFICATION OF EXPLANATION
I certify that I have carefully explained the purpose and nature of this research to (participant’s name) in age-appropriate language. He/She has had the opportunity to discuss it with me in detail. I have answered all his/her questions and he/she provided the affirmative agreement (i.e. assent) to participate in this research.

Investigator’s Signature: _____
Date: _____

Marist Institutional Review Board
Protocol # S18-028
Consent Form Approved Until 3/15/20
Appendix E

Datavyu Coding Manual

Project Name:
**Measuring Functional Dexterity and Dual-Task Ability in Individuals with Parkinson's Disease as Compared to Healthy Peers**

Manual Author: Julie Fineman

Revised: 9/5/19

**Datavyu Coding Manual**

**Subject Demographic Information:**
*<ID>* subject code association with participant
*<AG>*: age
*<Gnd>*: sex
  - m = male
  - f = female
*<HD>* hand dominance
  - l = left
  - r = right
*<SO>* side of onset
  - l = left
  - r = right
*<GP>*: group
  - 1 = healthy control
  - 2 = parkinsons disease H&Y Stage I
  - 3 = parkinsons disease H&Y Stage II/III
*<HY>*: hoehn and yahr scale
  - 1 = stage one
  - 2 = stage two
  - 3 = stage three

**Condition**
*<CD>*: trial types
  - BL = baseline
  - DT = dual task condition
  - A = alphabet

**Movement Time**
*<TMT>*: movement time

*tmt:* total movement time
  - **onset:** first finger movement to first coin contact
  - **offset:** fingers release all contact with the last (8th) coin
Coin One
<movement segment>:

a: first finger movement to coin contact
   <onset>: first finger movement on the non-dominant hand
   <offset>: last frame of downward motion of first finger to contact to coin/or first
   finger to contact coin

b: coin lift
   <onset>: frame after <a> offset
   <offset>: coin completely off support surface

c: coin contact to bilateral hands on coin
   <onset>: frame after <b> offset
   <offset>: frame where fingers from both hands are contacting coin

d: coin transfer
   <onset>: frame after <c> offset
   <offset>: first frame when non dominant hand releases the coin

e: coin transport
   <onset>: frame after <d> offset
   <offset>: last frame of movement to where coin is positioned over the slot in box/
   velocity slows/coin is clear

f: coin release
   <onset>: frame after <e> offset
   <offset>: coin no longer visible

Coin Two
<movement segment>:

a: finger movement to coin contact
   <onset>: second frame of movement of the non-dominant hand towards the next
   coin after <d1> offset
   <offset>: last frame of downward motion of first finger to contact to coin/or first
   finger to contact coin

b: coin lift
   <onset>: frame after <a> offset
   <offset>: coin completely off support surface

c: coin contact to bilateral hands on coin
   <onset>: frame after <b> offset
   <offset>: frame where fingers from both hands are contacting coin

d: coin transfer
   <onset>: frame after <c> offset
   <offset>: first frame when non dominant hand releases the coin
e: coin transport
   onset: frame after <d> offset
   offset: last frame of movement to where coin is positioned over the slot in box/
   velocity slows/coin is clear

f: coin release
   onset: frame after <e> offset
   offset: coin no longer visible

Coin Three
<movement segment>:

a : finger movement to coin contact
   onset: second frame of movement of the non-dominant hand towards the next
   coin after <d2> offset
   offset: last frame of downward motion of first finger to contact to coin/or first
   finger to contact coin

b: coin lift
   onset: frame after <a> offset
   offset: coin completely off support surface

c: coin contact to bilateral hands on coin
   onset: frame after <b> offset
   offset: frame where fingers from both hands are contacting coin

d: coin transfer
   onset: frame after <c> offset
   offset: first frame when non dominant hand releases the coin

e: coin transport
   onset: frame after <d> offset
   offset: last frame of movement to where coin is positioned over the slot in box/
   velocity slows/coin is clear

f: coin release
   onset: frame after <e> offset
   offset: coin no longer visible

Coin Four
<movement segment>:

a : finger movement to coin contact
   onset: second frame of movement of the non-dominant hand towards the next
   coin after <d3> offset
   offset: last frame of downward motion of first finger to contact to coin/or first
   finger to contact coin
b: coin lift  
   *onset:* frame after <a> offset  
   *offset:* coin completely off support surface

c: coin contact to bilateral hands on coin  
   *onset:* frame after <b> offset  
   *offset:* frame where fingers from both hands are contacting coin

d: coin transfer  
   *onset:* frame after <c> offset  
   *offset:* first frame when non dominant hand releases the coin

e: coin transport  
   *onset:* frame after <d> offset  
   *offset:* last frame of movement to where coin is positioned over the slot in box/velocity slows/coin is clear

f: coin release  
   *onset:* frame after <e> offset  
   *offset:* coin no longer visible

**Coin Five**

<movement segment>:

a: finger movement to coin contact  
   *onset:* second frame of movement of the non-dominant hand towards the next coin after <d4> offset  
   *offset:* last frame of downward motion of first finger to contact to coin/or first finger to contact coin

b: coin lift  
   *onset:* frame after <a> offset  
   *offset:* coin completely off support surface

c: coin contact to bilateral hands on coin  
   *onset:* frame after <b> offset  
   *offset:* frame where fingers from both hands are contacting coin

d: coin transfer  
   *onset:* frame after <c> offset  
   *offset:* first frame when non dominant hand releases the coin

e: coin transport  
   *onset:* frame after <d> offset  
   *offset:* last frame of movement to where coin is positioned over the slot in box/velocity slows/coin is clear
f: coin release
   onset: frame after <e> offset
   offset: coin no longer visible

Coin Six
<movement segment>:
  a: finger movement to coin contact
     onset: second frame of movement of the non-dominant hand towards the next
            coin after <d5> offset
     offset: last frame of downward motion of first finger to contact to coin/or first
            finger to contact coin

  b: coin lift
     onset: frame after <a> offset
     offset: coin completely off support surface

  c: coin contact to bilateral hands on coin
     onset: frame after <b> offset
     offset: frame where fingers from both hands are contacting coin

  d: coin transfer
     onset: frame after <c> offset
     offset: first frame when non dominant hand releases the coin

  e: coin transport
     onset: frame after <d> offset
     offset: last frame of movement to where coin is positioned over the slot in box/
            velocity slows/coin is clear

  f: coin release
     onset: frame after <e> offset
     offset: coin no longer visible

Coin Seven
<movement segment>:
  a: finger movement to coin contact
     onset: second frame of movement of the non-dominant hand towards the next
            coin after <d6> offset
     offset: last frame of downward motion of first finger to contact to coin/or first
            finger to contact coin

  b: coin lift
     onset: frame after <a> offset
     offset: coin completely off support surface

  c: coin contact to bilateral hands on coin
     onset: frame after <b> offset
     offset: frame where fingers from both hands are contacting coin
d: coin transfer
  onset: frame after <c> offset
  offset: first frame when non dominant hand releases the coin

e: coin transport
  onset: frame after <d> offset
  offset: last frame of movement to where coin is positioned over the slot in box/
  velocity slows/coin is clear

f: coin release
  onset: frame after <e> offset
  offset: coin no longer visible

Coin Eight
<movement segment>:

a : finger movement to coin contact
  onset: second frame of movement of the non-dominant hand towards the next
  coin after <d7> offset
  offset: last frame of downward motion of first finger to contact to coin/or first
  finger to contact coin

b: coin lift
  onset: frame after <a> offset
  offset: coin completely off support surface

c: coin contact to bilateral hands on coin
  onset: frame after <b> offset
  offset: frame where fingers from both hands are contacting coin

d: coin transfer
  onset: frame after <c> offset
  offset: first frame when non dominant hand releases the coin

e: coin transport
  onset: frame after <d> offset
  offset: last frame of movement to where coin is positioned over the slot in box/
  velocity slows/coin is clear

f: coin release
  onset: frame after <e> offset
  offset: coin no longer visible
Alphabet
<letter>
a: correct letter 1
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

b: correct letter 2
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

c: correct letter 3
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

d: correct letter 4
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

e: correct letter 5
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

f: correct letter 6
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

g: correct letter 7
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

h: correct letter 8
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

i: correct letter 9
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

j: correct letter 10
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

k: correct letter 11
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized

l: correct letter 12
  *onset*: when letter is vocalized
  *offset*: same when letter is vocalized
m: correct letter 13
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized

n: correct letter 14
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized

o: correct letter 15
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized

p: correct letter 16
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized

q: correct letter 17
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized

r: correct letter 18
  \textbf{onset}: when letter is vocalized
  \textbf{offset}: same when letter is vocalized
Pilot Data Summary

Pilot data was collected for four subjects with PD. The goal of the pilot data was to determine if individuals with PD could tolerate all of the various tests during one session, if instructions were clear, if testing procedures were consistent and most importantly, to determine which cognitive task should be used for the dual task condition of the C3t. The initial version of the C3t used with the HD population used recitation of the full alphabet as the secondary task in the C3t dual task condition. Early pilot data completed one year ago indicated that this task appear too easy and did not impose significant cognitive challenge. Reciting the full alphabet is something we have done since childhood. Early pilot subjects (healthy and PD) tried to sing the alphabet song and entrain the letters to the rhythm of the movement. Other options included recitation of every other letter of the alphabet as quickly as possible, or a verbal fluency test where participants alternately listed a piece of fruit and a piece of furniture. During this recent pilot data collection, two subjects were tested using every other letter of the alphabet and two subjects were tested using alternating listing of fruit and furniture.

Patient demographic information along with some of the baseline test data is presented in Table 2. Subjects were male and ranged in age from 62-75 years of age. Subjects were all right hand dominant and fell into H&Y stages I (n=2), II (n=1) and III (n=1). All subjects were tested 1-1.5 hours after taking the PD medication and reporting that they felt optimally medicated. UPDRS data was not requested from the treating neurologists at this time, as the n was too small for statistical analyses. All subjects met inclusion/exclusion criteria.
Table 2. Pilot subject demographic and baseline test data

<table>
<thead>
<tr>
<th></th>
<th>Subject #1</th>
<th>Subject #2</th>
<th>Subject #3</th>
<th>Subject #4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>62</td>
<td>72</td>
<td>75</td>
<td>75</td>
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<tr>
<td>Gender</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Dominant Hand</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Side of Onset</td>
<td>R</td>
<td>L</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Hoehn &amp; Yahr</td>
<td>II</td>
<td>I</td>
<td>III</td>
<td>I</td>
</tr>
<tr>
<td>UPDRS - III</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>MoCA</td>
<td>26</td>
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<td>27</td>
<td>25</td>
</tr>
<tr>
<td>Dext Q-T</td>
<td>31</td>
<td>27</td>
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<td>29</td>
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<tr>
<td>FDT (D/ND)</td>
<td>41.2/35.3</td>
<td>43.1/52.6</td>
<td>35.5/47.7</td>
<td>41.6/39.4</td>
</tr>
<tr>
<td>Cognitive Task</td>
<td>E/O letter of alphabet</td>
<td>E/O letter of alphabet</td>
<td>Alternating fruit &amp; furniture</td>
<td>Alternating fruit &amp; furniture</td>
</tr>
</tbody>
</table>

All four subjects completed all required tests without reports of fatigue or discomfort. Subjects reported understanding of all instructions and were able to follow instructions without apparent difficulty.

Total C3t scores were calculated for all subjects across baseline, complex and dual task conditions (Figure 9). All subjects demonstrate decreasing performance outcomes (higher scores to lower scores) from baseline to complex to dual task conditions, indicating that the dual task condition is the most challenging. Interestingly, subjects 2 and 4 present with mild disease severity (H&Y I) and subjects 1 and 3 present with moderate disease severity (H&Y II/III). It is clear from figure 9 that the subjects with moderate severity have greater change between baseline and dual task conditions that do the subjects with mild disease. Perhaps indicating the
C3t dual task condition is more challenging for individuals as the disease progresses and is able to differentiate disease severity.

Subjects 1 and 2 had the every other letter of the alphabet as their secondary task where subjects 3 and 4 had alternating fruit and furniture.

*Figure 9.* Subject C3t total scores across all three testing conditions.

Coincidentally, subjects 1 and 2 start off at a lower level of baseline performance than do subjects 3 and 4. To determine if one secondary task was more difficult than the other, we examined percent change between conditions (Figure 10). Despite having different secondary tasks, subjects 1 and 3 have an almost identical pattern of performance. Similarly, subjects 3 and 4 present with very similar performance patterns. This observation indicates that the two cognitive tasks are of similar difficulty. This being the case, we will choose every other letter of the alphabet as the cognitive task in the final study. This is because subjects appeared frustrated by the fruit and furniture condition, stating the task was difficult before even attempting it. Subjects seemed to run out of furniture words much sooner than
fruit words and there is a possibility that may be cultural differences in descriptions of furniture.

Figure 10. Percent change scores between total score outcomes across conditions for each subject.

Dual task cost measures calculated for both cognitive and motor performance on the dual task TUG are plotted on the graph directly below (Figure 11). Dual task cost measures calculated for both cognitive and motor performance on the C3t dual task condition are plotted on the second graph below (Figure 12). The two plots are visually different indicating different patterns of prioritization between the C3t and tug tasks. In Figure 11 – TUG measures: Subjects 1 and 3 (H&Y II/II) demonstrate mutual interference for both tasks. Subjects 2 and 4 (H&Y I) demonstrate a trade-off during the dual task TUG with subject #4 demonstrating a cognitive-priority trade off (DTB in cognition, DTC in TUG performance) and subject #3 demonstrating a mild gait-priority trade off (DTB in TUG performance with DTC on cognitive task).
Figure 11. Motor and cognitive DTC measure for TUG task.

During the C3t dual task condition (Figure 12), all subject demonstrate mutual interference on both tasks with the moderately impaired subjects demonstrating greater mutual interference than the subjects with mild disease severity.
At first glance, with a small n, it can be seen that task prioritization differs between the TUG and the C3t in the subjects with mild impairment (H&Y I). The subjects with moderate impairment (H&Y II/III) demonstrate a similar pattern of mutual interference across both tasks, with higher levels of interference occurring during the C3t.

**Changes made as the result of pilot testing.**

Over the course of pilot data gathered last year and this current pilot data, I have realized/changed a number of things as listed below:

- Choice of secondary task for the C3t DT condition (switched from recitation of the full alphabet to recitation of every other letter of the alphabet)
- Realization that there is a learning effect during the C3t baseline condition and one practice trial is required to reach an accurate baseline level of performance.
Early pilot data piloted the movement component analysis using Datavyu, allowing for the development of the movement segment rules and necessitating a start position of both hands on the table to be able to visualize movement start time.

Also – initial recording at 60 hz presented with a frequently blurry image necessitating the purchase of a camera that could film at 120hz, eliminating this issue and allowing for more accurate video coding.

Early pilot data also made it clear that it was difficult to hear individuals with PD during the filming, due to low voice volume. Tara shared the idea of a Bluetooth microphone and receiver pair that connect to the recorder and input the voice. These have been purchased and this was a non-issue with these current subjects.

This current pilot session clarified some test instruction inconsistencies, which have been clarified for a more consistent performance.

One pilot subject, when presented with the Stroop test, told me that he was colorblind – necessitating a change in the exclusion criteria.
Appendix G
Clinch Token Transfer Test (C3t) Manual

THE CLINCH TOKEN TRANSFER TEST

Authors: Susanne Clinch, Monica Busse, Mariah Lelos, Anne Rosser

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INTRODUCTION

The Clinch token transfer test (C3t) is a brief, standardized clinical assessment tool that is used to quantify upper extremity function.

Briefly, the subject is seated at a table in front of the C3t test kit. The kit contains three sets of tokens and a purpose manufactured container.

When instructed, the subject is required to complete a series of token transfer activities. The subject is asked to pick up a token and transfer it from their dominant to their non-dominant hand. Tokens are either transferred in order of size (Baseline Transfer) or value, without or whilst reciting the alphabet (Complex Transfer and Dual Transfer) where the addition of cognitive load increases the task complexity. The time taken to pick up and transfer the tokens to the C3t container as well as the number of errors are recorded.

This manual describes the setup and testing procedures required to administer the Clinch token transfer test (C3t).

C3t EQUIPMENT

All the equipment needed to conduct the C3t is provided as part of the C3t test kit (see Figure 1). This includes:

a. C3t container
b. Three magnetic token trays, one for each of the tasks (Baseline, Complex and Dual tasks)

c. Eight magnetic tokens for each of the tasks (see Figure 2):
   i. Baseline Transfer (circle indentations on rear). No value is printed on participant facing side.
   ii. Complex Transfer (diamond indentations on rear). The values 200, 100, 50, 20, 10, 5, 2, 1 are printed on the participant facing side.
   iii. Dual Transfer (triangle indentations on rear). The values 90, 82, 71, 49, 35, 17, 6, 3 are printed on the participant facing side.

d. and e. Two Baseline Value cards
e. C3t case

A stop watch, table and hard back chair are required for conducting the test, but are not provided with the C3t test kit.
Figure 1: C3t test components
Figure 2: Token order for the Baseline Transfer, Complex Transfer and Dual Transfer tasks.
PROCEDURE FOR SETTING UP THE C3t EQUIPMENT

1. Lay the C3t test kit open onto a flat surface as shown in Figure 3 below.

2. If the subject is right handed, the circular indentation should be positioned on the right side of the case. If the subject is left handed, make sure that the circular indentation is on the left side of the case.

3. Place the C3t container upright in the circular indentation, ensuring that the slot is vertical to the participant.

4. Remove the elastic band that stretches around the trays when the C3t test kit is stored.

5. Match the circular, diamond and triangle patterned tokens with the patterned indentations on the token trays (Figure 2).

6. Stack the trays onto the stepped grooves in the C3t case, ensuring that the largest token is furthest away from the subject.

   The trays should be stacked as described below:

   i. Insert the tray with the triangle indents in first. This is for the Dual Transfer task.

   ii. Position the tray with the diamond indents on top of the first tray. This is for the Complex Transfer task.

   iii. Lay the complex value card on top (featuring numbers 49, 82, 6, 90, 35, 71, 3, 17)

   iv. Lay the Baseline Value card on top of this (featuring 20, 1, 10, 200, 2, 5, 50, 100).

   v. Position the tray with the tokens that have no values (circle indents) on top. This is for the Baseline Transfer task.

Figure 3: C3t kit set up
TEST PROCEDURE

The subject is asked to sit on a hard backed chair with the C3t positioned in front of them on a table. Ensure that the C3t is set up correctly for either a right or left handed subject.

The complete C3t assessment requires the subject to complete six tasks; three involving the transfer of tokens, Baseline Transfer, Complex Transfer and Dual Transfer tasks and three involving verbal tasks. A C3t scoring sheet is provided with this manual in which you should record time taken and number of errors for each of the tasks.

THE PROCEDURE AND THE C3t TASK ORDER IS DESCRIBED BELOW.

1 Baseline Transfer task: The subject is asked to transfer the first row of tokens, in order of size, starting with the largest token, as quickly as possible. This should be fairly simple for the subject as the tokens are already positioned in front of them in size order. The largest token should be located furthest away from the subject when they are seated at the table.

2 Baseline Value: The top tray is removed to reveal the baseline value card. The subject is shown eight values (20, 1, 10, 200, 2, 5, 50, 100) and asked to recite the values in numerical order from the highest to the lowest value. This test is to ensure the subject can count backwards using the same values that will be presented on the tokens in the Complex Transfer task.

3 Complex Value: The baseline value card is removed to reveal the complex value card. Eight different, more complex values are presented (49, 82, 6, 90, 35, 71, 3, 17). The subject is asked to recite the values in numerical order from the highest to the lowest value. This test is to ensure the subject can count backwards using the same values that will be presented in the Dual Transfer task.

4 Baseline Alphabet: The subject is asked to recite the alphabet as quickly as possible. The subject can recite the alphabet in any language, as long as the researcher can record the number of correct and incorrect letters recited. This baseline test is carried out in preparation for the Dual Transfer task.

5 Complex Transfer task: The subject is asked to transfer the tokens in order of value from highest to lowest. The tokens must remain covered whilst the test instructions are read to ensure the subject does not attempt to determine the token order before the timing of the task begins.

6 Dual Transfer task: The subject is asked to transfer the tokens in order of value from highest to lowest whilst continuously reciting the alphabet as quickly as possible. Again, the tokens must remain covered whilst the test instructions are read to ensure the subject does not start working out the token order before the test begins.
VERBAL INSTRUCTIONS FOR EACH TASK

The subject is asked to sit facing the table, with the C3t set up in front of them. They should start with their hands placed on their legs.

The following instructions are given for each task:

1. Baseline Transfer task:
   When I say “Go,” using your non-dominant hand I want you to pick up each token individually, pass it to your dominant hand and put it in the container. I want you to start with the largest token, so the one furthest from you and work your way down to the smallest token which is closest to you. I want you to do this as quickly as possible and I will stop timing you after you have placed the last token into the container. If you drop a token and it falls or rolls outside of this area (indicate the outer edge of the C3t case to the subject), please leave it and move onto your next token. If you drop the token and it falls on the surface in front of you (indicate that this is within the foam of the C3t case), you can pick it up and continue. I would like you to start with your hands on your legs. Do you have any questions? Ready? Go*

2. Baseline Value task
   “Using the values printed on this card, I want you to say aloud the highest value and work your way in decreasing order of value to the lowest value. I want you to do this as quickly as you can and I will stop timing you once you have said the final value. Do you have any questions? Ready? Go”*

3. Complex Value task
   “Using the values printed on this card, I want you to say aloud the highest value and work your way in order to the lowest value. I want you to do this as quickly as you can and I will stop timing you once you have announced your final value. Do you have any questions? Ready? Go.”

4. Baseline Alphabet task
   “I would like you to recite the alphabet, pronouncing each letter, as quickly as possible. I will stop timing you once you have said your final letter. Do you have any questions? Ready? Go”*

5. Complex Transfer task
   (Keep the tokens covered using the Complex value card whilst reading the instructions) “When I say “Go,” using your non-dominant hand I want you to pick up each token individually, pass it to your dominant hand and put it in the container. I want you to transfer the tokens in order of value, starting with the highest value and ending with the lowest. I want you to do this as quickly as possible and I will stop timing you after you have released the last token into the container. If you drop a token and it falls or rolls outside of this area (indicate the outer edge of the C3t case to the subject), please leave it and move onto your next token. If you drop the token and it falls on the surface in front of you (indicate that this is within the foam of the C3t case), you can pick it up and continue. I would like you to start with your hands on your legs. Do you have any questions? Ready? Go” (Remove the Complex value card to reveal the tokens).

6. Dual Transfer task
   (Keep the tokens covered using the empty Complex transfer task token tray whilst reading the instructions) “When I say “Go,” using your non-dominant hand I want you to pick up each token individually, pass it to your dominant hand and put it in the container. I want you to transfer the tokens as quickly as possible in order of value, starting with the highest value and ending with the lowest value. Whilst doing this I want you to recite the alphabet as quickly as you can. If you finish the alphabet before you finish this transfer task, start reciting the alphabet again and keep doing this until you have placed the last token into the container. If you drop a token and it falls or rolls outside of this area (indicate the outer edge of the C3t case to the subject), please leave it and move onto your next token. If you drop the token and it falls on the surface in front of you (indicate that this is within the foam of the C3t case), you can pick it up and continue. I would like you to start with your hands on your legs. Do you have any questions? Ready? Go” (Remove the complex transfer task token tray to reveal the tokens).
SCORING THE C3t

The time to complete the Baseline Transfer task, Complex Transfer task and dual transfer task is recorded in seconds. The researcher should start timing as soon as the subject is instructed to “Go” and stop as soon as the last token is released from the subject’s fingers into the container.

The researcher should observe the subject whilst performing the C3t and record any of the following errors:

- If the subject does not transfer the tokens correctly (from non-dominant to dominant) between their hands this is recorded as a transfer error.
- If the subject transfers the tokens in the wrong order this is recorded as a rule error.
- If the subject drops a token and this falls outside of the C3t case, remind the subject to leave it and to continue with the next token. Record this as a token dropped out of reach. If the token is dropped out of reach but the subject quickly retrieves it with little test disturbance, then record this as a rule error. Refer to the FAQ section for further information.

For each task, the time taken and any errors committed are combined to calculate a total score for that task i.e. Baseline Transfer, Complex Transfer and Dual Transfer tasks.

The following variables are generated during the performance of the C3t. A set of formulas within a spreadsheet are available from the developers to assist with the automatic rating of the C3t, however Table 1 below provides a summary of the variable description and method to produce the variable in the equation column. If the score is simply recorded as observed during test performance, this is indicated as a shaded out section in the table below.

Table 1: C3t variables and scoring methods

<table>
<thead>
<tr>
<th>Variable Name</th>
<th>Short Variable Name</th>
<th>Variable Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Transfer dropped</td>
<td>C3TBTRAN_DROP</td>
<td>Number of tokens dropped or rolled out of reach in Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Rule errors</td>
<td>C3TBTRAN_ERR</td>
<td>Number of errors committed in the Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Transfer errors</td>
<td>C3TBTRAN_TRANERR</td>
<td>Number of transfer errors committed in the Baseline Transfer</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Task accuracy</td>
<td>C3TBTRAN_ACCURACY</td>
<td>Percentage accuracy based on the number of errors committed in the Baseline Transfer task. = task accuracy (%) = (16 - combined number of transfer and rule errors) / 16 * 100</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>C3TBTRAN_TIME</td>
<td>Time taken (s) to complete the Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
</tbody>
</table>
SCORING THE C3t

The time to complete the Baseline Transfer task, Complex Transfer task and dual transfer task is recorded in seconds. The researcher should start timing as soon as the subject is instructed to “Go” and stop as soon as the last token is released from the subject’s fingers into the container.

The researcher should observe the subject whilst performing the C3t and record any of the following errors:

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<tr>
<th>Variable Name</th>
<th>Short Variable Name</th>
<th>Variable Description</th>
<th>Equation</th>
</tr>
</thead>
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<tr>
<td>Baseline Transfer</td>
<td>C3TBTRN_</td>
<td>Number of tokens dropped or rolled out of reach in Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>dropped tokens</td>
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<td></td>
</tr>
<tr>
<td>Baseline Transfer</td>
<td>C3TBTRN_</td>
<td>Number of rule errors committed in the Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>rule errors</td>
<td>RULEERR</td>
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<td></td>
</tr>
<tr>
<td>Baseline Transfer</td>
<td>C3TBTRN_</td>
<td>Number of transfer errors committed in the Baseline Transfer</td>
<td>Recorded as observed</td>
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<td>TRANERR</td>
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</tr>
<tr>
<td>Baseline Transfer</td>
<td>C3TBTRN_</td>
<td>Percentage accuracy based on the number of errors committed in the Baseline Transfer task</td>
<td>Task accuracy (%) = 16-combined number of transfer and rule errors / 16 * 100</td>
</tr>
<tr>
<td>task accuracy</td>
<td>ACCURACY</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Transfer</td>
<td>C3TBTRN_</td>
<td>Time taken (s) to complete the Baseline Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>time</td>
<td>TIME</td>
<td></td>
<td></td>
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<tr>
<td>Variable Name</td>
<td>Short Variable Name</td>
<td>Variable Description</td>
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</tr>
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<tr>
<td>Baseline Transfer total task score</td>
<td>C3TBTNANO.</td>
<td>Total task score based on the time taken (s) and the number of errors made in the Baseline Transfer task.</td>
<td>Task accuracy (%) = Number of tokens dropped out of reach / task accuracy</td>
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<td>Baseline Value correct values</td>
<td>C3TBVAL.</td>
<td>Number of correct values (out of 8) in the Baseline Value task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Baseline Value accuracy</td>
<td>C3TBVAL.</td>
<td>Percentage accuracy in the Baseline Value task.</td>
<td>Baseline Value accuracy (%) = Correct values / 8 * 100</td>
</tr>
<tr>
<td>Baseline Value time</td>
<td>C3TBVAL.</td>
<td>Time (s) taken to complete the Baseline Value task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Complex Value correct values</td>
<td>C3TCPV.</td>
<td>Number of correct values (out of 8) in the Complex Value task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Complex Value accuracy</td>
<td>C3TCPV.</td>
<td>Percentage accuracy in the Complex Value task.</td>
<td>Baseline Value accuracy (%) = Correct values / 8 * 100</td>
</tr>
<tr>
<td>Complex Value time</td>
<td>C3TCPV.</td>
<td>Time taken (s) to complete the Complex Value task.</td>
<td>Recorded as observed</td>
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<td>Baseline Alphabet correct letters</td>
<td>C3TBALPH.</td>
<td>Number of correct letters of the alphabet recited in the Baseline Alphabet task.</td>
<td>Recorded as observed</td>
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<tr>
<td>Baseline Alphabet accuracy</td>
<td>C3TBALPH.</td>
<td>Percentage accuracy in the Baseline Alphabet task.</td>
<td>Alphabet accuracy (%) = Correct letters / Total number of letters in the alphabet * 100</td>
</tr>
<tr>
<td>Baseline Alphabet time</td>
<td>C3TBALPH.</td>
<td>Time taken (s) to complete the Baseline Alphabet task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Baseline Alphabet correct letters/second</td>
<td>C3TBALPH.</td>
<td>Number of correct letters of the alphabet recited per second in the Baseline Alphabet task.</td>
<td>Correct letters per second = Correct letters / Alphabet time (s)</td>
</tr>
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<td>Complex Transfer dropped tokens</td>
<td>C3TCPV.</td>
<td>Number of tokens dropped or rolled out of reach in the Complex Transfer task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Complex Transfer rule errors</td>
<td>C3TCPV.</td>
<td>Number of rule errors committed in the Complex Transfer task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Variable Name</td>
<td>Short Variable Name</td>
<td>Variable Description</td>
<td>Equation</td>
</tr>
<tr>
<td>---------------</td>
<td>---------------------</td>
<td>----------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Complex Transfer error</td>
<td>C3TCTRAN_TRANERR</td>
<td>Number of transfer errors committed in the Complex Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Complex Transfer test accuracy</td>
<td>C3TCTRAN_ACCURACY</td>
<td>Test accuracy based on the number of errors committed in the Complex Transfer task</td>
<td>Task accuracy (%) = 16-combined number of transfer and rule errors / 16 * 100</td>
</tr>
<tr>
<td>Complex Transfer time</td>
<td>C3TCTRAN_TIME</td>
<td>Time taken (s) to complete the Complex Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Complex Transfer total task score</td>
<td>C3TCTRAN_SCORE</td>
<td>Total score based on the time taken and the number of errors committed in the Complex Transfer task</td>
<td>Total task score = B-number of tokens dropped out of reach time (s) * task accuracy</td>
</tr>
<tr>
<td>Baseline-Complex performance cost (time)</td>
<td>C3TBCCOST_TIME</td>
<td>Time percentage cost between the C3t Baseline Transfer task vs the Complex Transfer task</td>
<td>Baseline-Complex performance cost (time) = Complex Transfer task time - Baseline Transfer task time / Baseline Transfer task time * 100</td>
</tr>
<tr>
<td>Baseline-Complex performance cost (total task score)</td>
<td>C3TBCCOST_SCORE</td>
<td>Total score percentage cost between the Baseline Transfer task vs the Complex Transfer task</td>
<td>Baseline-Complex performance cost (total task score) = Baseline Transfer total task score - Complex Transfer total task score / Baseline Transfer total task score * 100</td>
</tr>
<tr>
<td>Dual Transfer dropped tokens</td>
<td>C3TDTRAN_DROP</td>
<td>Number of tokens dropped or rolled out of reach in the Dual Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Dual Transfer rule errors</td>
<td>C3TDTRAN_RULEERR</td>
<td>Number of rule errors committed in the Dual Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Dual Transfer transfer errors</td>
<td>C3TDTRAN_TRANERR</td>
<td>Number of transfer errors committed in the Dual Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Dual Transfer test accuracy</td>
<td>C3TDTRAN_ACCURACY</td>
<td>Test accuracy based on the number of errors committed in the Dual Transfer task</td>
<td>Task accuracy (%) = 16-combined number of transfer and rule errors / 16 * 100</td>
</tr>
<tr>
<td>Dual Transfer time</td>
<td>C3TDTRAN_TIME</td>
<td>Time taken (in seconds) to complete the Dual Transfer task</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Variable Name</td>
<td>Short Variable Name</td>
<td>Variable Description</td>
<td>Equation</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------------------</td>
<td>---------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dual Transfer total task score</td>
<td>C3TDTRAN_SCORE</td>
<td>Total score based on the time taken and the number of errors committed in the Dual Transfer task</td>
<td>Total task score = ( \frac{8 \times \text{number of tokens dropped out of reach}}{\text{time (s)}} ) * task accuracy</td>
</tr>
<tr>
<td>Dual Task alphabet correct letters</td>
<td>C3TDALPH_CORRECT</td>
<td>Number of correct letters of the alphabet recalled in the Dual Transfer task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Dual Task alphabet accuracy</td>
<td>C3TDALPH_ACCURACY</td>
<td>Percentage accuracy in the Dual Transfer task</td>
<td>Alphabet accuracy = ( \frac{\text{correct letters}}{\text{total number of letters in the alphabet}} ) * 100</td>
</tr>
<tr>
<td>Dual Task alphabet time</td>
<td>C3TDALPH_TIME</td>
<td>Time taken (seconds) to complete the alphabet in the Dual Transfer task.</td>
<td>Recorded as observed</td>
</tr>
<tr>
<td>Dual Task correct letters/ second</td>
<td>C3TDALPH_CORRECTSEC</td>
<td>Number of correct letters of the alphabet recalled per second in the Dual Transfer task</td>
<td>Correct letters per second = ( \frac{\text{correct letters}}{\text{Dual Transfer task time (s)}} )</td>
</tr>
<tr>
<td>Complex-Dual performance cost (time)</td>
<td>C3TCDICOST_TIME</td>
<td>Time percentage cost between the C3t Baseline Transfer vs the Dual Transfer task</td>
<td>( \text{PC} = \frac{\text{Dual Transfer task time - Baseline Transfer task time}}{\text{Dual Transfer task time}} ) * 100</td>
</tr>
<tr>
<td>Complex-Dual performance cost (total task score)</td>
<td>C3TCDICOST_SCORE</td>
<td>Total score percentage cost between the C3t Baseline Transfer vs the Dual Transfer task</td>
<td>( \text{PC} = \frac{\text{Baseline Transfer total task score} - \text{Dual Transfer total task score}}{\text{Baseline Transfer total task score}} ) * 100</td>
</tr>
<tr>
<td>Complex-Dual performance cost (alphabet)</td>
<td>C3TCDICOST_ALPH</td>
<td>Correct letters per second percentage cost between the Alphabet Baseline vs the Dual Transfer task</td>
<td>( \text{PC} = \frac{\text{Baseline Alphabet correct letters} - \text{Dual task alphabet correct letters}}{\text{Baseline Alphabet correct letters}} ) * 100</td>
</tr>
</tbody>
</table>

\( \text{PC} = \) performance cost

---

Whilst the subject performs the C3t Baseline Transfer, Complex Transfer and Dual Transfer task, the assessor records the number of transfer and rule errors committed. To calculate performance accuracy they subtract the number of errors from 16 (equivalent to 8 possible transfer errors + 8 possible rule errors), divide by 16 and multiply by 100.

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To calculate the C3t total score they subtract the number of tokens dropped out of reach from 8 (8 tokens), divide this by the time taken to complete the C3t, and then multiply by the performance accuracy. A higher score is indicative of better performance, suggesting a faster time and/or fewer errors.
FREQUENTLY ASKED QUESTIONS (FAQS)

How do I fold away the C3t?

Remove the container and place it into the holder located on the side crease of the C3t case. Next, place the tokens into the correct position on the correct tray. Stack the token trays and value cards in the same order they were setup and stretch the elastic band length way around the token trays to secure them in place. Fold end of the assessment case that holds the token trays to the centre, fold the final side of the case and push the poppers to secure it.

What if the subject drops a token on the floor?

If a token is dropped outside the C3t case or on the floor, remind the subject to leave it and continue with the next token. Record the number of tokens dropped out of reach and use this in the equation to calculate the C3t total score.

What if the subject drops a token outside the C3t case but quickly retrieves it?

If the token is dropped just outside the container or on the subject’s lap and the subject retrieves the token immediately then do not count this as a ‘dropped token’. Instead, the assessor should record this as a rule error, as the subject has not ignored the dropped token as instructed.

What if the subject starts transferring the tokens in the wrong order or forgets to transfer the tokens between their hands?

After the first error has been made, the assessor can remind the subject of the rules once by saying for example, ‘remember to transfer the token between your hands’ or ‘remember to transfer the token from the highest value to the lowest.’

What if the subject forgets the alphabet or stops reciting the alphabet halfway through the C3t dual task?

If the subject forgets the alphabet (after 5 seconds of silence), the assessor can repeat the last letter the subject recited. If this does not trigger a response then the researcher can recite the beginning letter of the alphabet, hinting for the subject to start again. Although the main aim of the C3t dual task is that the subject recites the alphabet whilst transferring the tokens, the assessor can help the subject with the alphabet only once.

What if the subject commits a lot of errors in the baseline tasks?

Depending on the population being tested, it is advisable researchers validate criteria, which subjects have to pass before continuing to the next, more complex item. For example, achieving 75% accuracy in the alphabet baseline before continuing to the C3t dual task.

Who can I contact if I have any questions?

You can contact the developers at the Centre for Trials Research, Cardiff University by email: c3t@cardiff.ac.uk
# DATA COLLECTION SHEET

<table>
<thead>
<tr>
<th>Subject ID</th>
<th>Date</th>
<th>Assessor (s)</th>
</tr>
</thead>
</table>

**DOB:**

**Gender:** Male / Female  (delete as appropriate)

**Right / Left handed** (delete as appropriate)
### Baseline Transfer Task

<table>
<thead>
<tr>
<th>Time taken (s)</th>
<th>Number of transfer errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of rule errors</td>
<td>Number of dropped tokens</td>
</tr>
<tr>
<td>Task attempted:</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Baseline Value Task

<table>
<thead>
<tr>
<th>Time taken (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempted:</td>
</tr>
</tbody>
</table>

Tokens: Correct order  
(mark each value recited correctly)  
200 100 50 20 10 5 2 1

### Complex Value Task

<table>
<thead>
<tr>
<th>Time taken (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task attempted:</td>
</tr>
</tbody>
</table>

Tokens: Correct order  
(mark each value recited correctly)  
90 82 71 49 35 17 6 3
4 Baseline Alphabet

Alphabet language: [ ]

Time taken (s) [ ] Number of correct letters [ ]

Task attempted: [ ] Yes [ ] No

Alphabet: Correct order
(mark each letter recited correctly)

A [ ] B [ ] C [ ] D [ ] E [ ] F [ ] G [ ] H [ ] I [ ] J [ ]
K [ ] L [ ] M [ ] N [ ] O [ ] P [ ] Q [ ] R [ ] S [ ] T [ ]
U [ ] V [ ] W [ ] X [ ] Y [ ] Z [ ]

5 Complex Transfer Task

Time taken (s) [ ] Number of transfer errors [ ]

Number of rule errors [ ] Number of dropped tokens [ ]

Task attempted: [ ] Yes [ ] No

Tokens: Correct order
(mark each value transferred correctly)

200 100 50 20 10 5 2 1
6 Dual Transfer Task

Time taken (s) ____________________________ Number of transfer errors ____________________________

Number of rule errors ____________________________ Number of dropped tokens ____________________________

Number of correct letters ____________________________

Task attempted: Yes No

Tokens: Correct order
(mark each value transferred correctly)

90 82 71 49 35 17 6 3

Alphabet Correct order
(mark each letter recited correctly during the task)

A B C D E F G H I J
K L M N O P Q R S T
U V W X Y Z

A B C D E F G H I J
K L M N O P Q R S T
U V W X Y Z

A B C D E F G H I J
K L M N O P Q R S T
U V W X Y Z

THE CLINCH TOKEN TRANSFER TEST