Sex differences in multi-tasking: Stroop effects on movement symmetry

Amy G. Cochrane

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I declare that this report is my own original work and that contributions of others have been duly acknowledged

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Amy G. Cochrane

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Abstract

There is a strong stereotype throughout the world that females are better at multi-tasking than males, despite mixed research evidence. A recent study involved simultaneous performance of a Stroop task with walking and found that young females suffered less consequence to movement than males and older females (Killeen et al., 2017). In the present study, 41 young adults (21 females) aged 18-40 participated in the study, performed a novel bimanual coordination task in an anti-phase movement pattern, while simultaneously performing a Stroop task. In contrast to Killeen and colleagues (2017) results, there were no differences between males and females in asymmetry as Stroop difficulty increased. One surprising difference was found in the frequency measure, whereby males and females increased frequency as Stroop difficulty increased, but females did not increase as much as males. This may be evidence of females being better at multi-tasking than males. Therefore, in line with the majority of multi-tasking research, the present study found limited evidence of sex differences in multi-tasking, and sex differences that were found had a small effect size.

People living in modern society engage in multi-tasking almost constantly to keep up with life's demands. It is commonplace to simultaneously cook dinner while talking on the phone or walk on the treadmill while reading a magazine. However, it is well known that multi-tasking leads to splitting cognitive resources between each task and can lead to poorer performance of both. This is reflected in laws that prohibit people from engaging in activities like driving whilst using a hand held mobile phone because this leads to a lapse in concentration and greater risk of being involved in an accident (Strayer & Drews, 2007). The processes and outcomes of multi-tasking have been extensively researched, with clear evidence of disadvantages when performing more than one task (Al Yahyah et al., 2011; Bowman, Levine, Waite & Gendrom, 2010; Pashler, Johnston & Ruthroff, 2001). However, the extent of the disadvantage has been suggested to depend on sex.

There is a well-believed stereotype that females are able to engage in multiple activities with less consequence to performance than males. Research has suggested that this stereotype is based on the idea that females have more practice at multi-tasking than males because females historically have tended to be more likely to juggle childcare with employment and household chores (Szameitat, Hamaida, Tulley, Saylik & Otermans, 2015). Recent research has provided evidence of an advantage for females over males in regard to multi-tasking, but this research is limited and has small effect sizes (Killeen et al., 2017; Stoet, O'Connor, Conner and Laws, 2013). Therefore, more research is needed to investigate sex differences in multi-tasking.

Multi-tasking research

Multi-tasking is the ability to perform two or more tasks concurrently and can refer to performing overlapping tasks (divided attention) or frequently switching between tasks (Szameitat et al., 2015). Research measuring the effects of instant messaging whilst completing a class reading found that students who read while instant messaging are slower to complete their readings; even after eliminating the time it took to write and send the instant message (Bowman et al., 2010). This is believed to be because of the psychological refractory period whereby psychological resources for the second task cannot commence for a period of time straight after the previous task has been completed (Pashler, Johnston & Ruthroff, 2001). This could additionally be because the last parts of the reading had been forgotten upon commencement of instant messaging, and these have to be re-read (Bowman et al., 2010).

Research has found similar deficits in task performance when two tasks are performed simultaneously and attention is divided. A meta-analysis conducted by Al-Yahya and colleagues (2011) reviewed studies that measured gait performance alone and while also performing a cognitive task. They found that when walking was paired with a second cognitive task, gait changes occurred including reduced speed, reduced stride length and increased stride variability (Al-Yahya et al., 2011). Furthermore, the effects of multi-tasking appear to be heightened in older adults, with older adults being significantly poorer at dividing attention between tasks (Al-Yahya, 2011; Killeen et al., 2017; McDowd & Craik, 1988). While there is consensus across the literature about these consequences of multi-tasking, sex differences are an area of debate.

Multi-tasking has typically been thought of as a skill attributed to females more than males in today's society. A study conducted by Stoet and colleagues (2013) argued that both males and females performed slower when they were multi-tasking compared to performing one task, but this slowing was significantly larger for males than females. Despite these conclusions, this study had a small effect size and is one of the few studies to find any evidence of sex differences. More recently, a meta-analysis conducted by Szameitat and colleagues (2015) found that despite a strong stereotype that females are better than males at multi-tasking, there is a very small body of research that has found evidence for this, and these studies only found small effect sizes (Szameitat et al., 2015). Rather, the majority appears to suggest that there are no differences in multi-tasking (Redick et al., 2012; Watson & Strayer, 2010). However, a recent study involving the simultaneous performance of walking and a Stroop task does support this hypothesis (Killeen et al. 2017).

Stroop paradigm

The Stroop paradigm is used to assess cognitive mechanisms involved in attention, working memory, facilitation, inhibition and interference (Macleod 1991; Milham et al, 2002; Bernal & Altman, 2009). A Stroop task generally involves a written word, which is printed in coloured ink, and the goal is to name the ink colour as quickly as possible while maintaining accuracy. There are three conditions in a colour Stroop task: neutral, congruent and incongruent. A neutral condition is one where the written word is colour neutral or a series of consonant letters that do not make up a word (Brown, 2011). A congruent condition is where the colour word and ink colour are the same, for example the word ‘Red’ is written in red ink (MacLeod, 1991). In contrast, an incongruent condition is one where the colour word and ink colour are different, for example the word ‘Red’ written in blue ink (MacLeod, 1991). Facilitation and interference are mechanisms involved in the Stroop task and occur through the written word.

The Stroop paradigm relies on reading, which is a fairly automatic process for the majority of people due to a large emphasis on reading during schooling and everyday life (MacLeod, 1991). As reading is largely automatic, reading the word in a Stroop task is faster than the less automatic task of identifying the ink colour (Dishon-Berkovits & Algom, 2000). This can have no effect, enhance, or impede performance of naming the ink colour, depending on the type of word in relation to the ink colour. A neutral Stroop condition is one where the written word is unrelated to colour semantically. The use of a neutral Stroop condition creates a baseline for naming the ink colour because there is believed to be no facilitation or interference from the written word. However, research has suggested that any written word creates interference in naming the ink colour in comparison to neutral conditions which use random consonant strings or a row of x's as the written stimuli (Kinshita, De Wit & Norris, 2017). This interference occurs when the written word is a real word, and also when it is a pseudo word (Kinshita, De Wit & Norris, 2017). The degree of facilitation and interference in congruent and incongruent trials is dependent on the type of neutral condition used as the baseline.

Facilitation and interference are the processes involved in the congruent and incongruent conditions respectively. Facilitation refers to the tendency for the written word to speed up processing of the ink colour when the word and ink colour are the same. Studies which base the neutral condition on real colour-neutral words show that a congruent condition does lead to facilitation of the written colour in identifying the ink because baseline interference is eliminated (Brown, 2011). In contrast, studies which base the neutral condition on consonant letter strings (XXXX) have suggested that facilitation only occurs when comparing a congruent condition to an incongruent condition (Kinshita, De Wit & Norris, 2017; Neill, 1977). That research has shown that when the same word and ink colour are presented together (congruent condition), there is less interference than when a different word colour and ink colour are presented together (incongruent condition), but still more interference than a neutral condition (XXXX) (Kinshita, De Wit & Norris, 2017; Neill, 1977). Despite this, there is good evidence that true facilitation does exist when multiple congruent trials are presented consecutively, rather than when congruent and incongruent trials are mixed in together (Milham et al., 2002). This occurs because adopting the strategy to simply read the colour words, which is incorrect in terms of what was instructed, actually leads to the correct response in these trials and is rewarded (Brown, 2011). However, this may still not be true facilitation because the task is completed by merely reading the word, rather than using the colour word to assist in naming the ink colour. Despite the facilitation debate, interference is a well understood phenomenon in Stroop studies.

Interference occurs whereby the written word interferes with naming the ink colour when the word and ink colour are different (MacLeod, 1991). Interference can be further manipulated by changing the sequence of Stroop stimuli in trials. A study conducted by Neil (1977) found that interference was heightened if the ink colour was the same as the directly preceding word colour, naming it the distractor-suppressor effect. This occurs because the colour of the word is suppressed, which makes it more difficult for that colour to then be activated. Another study conducted by Neil (1978, as cited in MacLeod, 1991) found that facilitation could also be manipulated in the same sort of way. Neil (1978, as cited in MacLeod, 1991) found that if the irrelevant word colour matched the immediately preceding ink colour, facilitation occurred. It is suggested that by naming the colour in the immediately preceding trial, it is easier to discard that as a possibility, which reduces the remaining possible colours (Neil, 1978 as cited in MacLeod, 1991; Notebaert and Soetens 2006). These findings suggest that Stroop interference can be manipulated, even within an incongruent condition. The ability to deal with interference in an incongruent condition relies on inhibition.

Efficient completion of a Stroop task relies on inhibition. Inhibition occurs through attentional control and is correlated with activity in areas throughout the prefrontal and parietal areas (Bernal & Altman, 2009; Milham et al., 2002). Milham and colleagues (2002) conducted an fMRI study whereby functional brain activity was measured while participants conducted a Stroop task. Milham and colleagues (2002) found that the dorsolateral prefrontal cortex was key to guiding attention in the task and suggested this worked in two ways. The first was by interacting with the ventrolateral prefrontal cortex early on to select which aspects of the stimulus held in working memory should be further processed and which should be ignored. The second was by regulating the activity of the posterior regions involved in processing, in order to increase processing in the systems deemed relevant to the task, and decrease processing in those that are not. However, interference does still occur because the automaticity of reading is very difficult to inhibit entirely, particularly for older adults.

Efficiency of completing a Stroop task is dependent on age, with older adults having more difficulty than younger people. Milham et al. (2002) found that in younger people, the prefrontal cortex enables attention and inhibition of stimuli, but this was diminished in older people. Older adults experience increases in interference when comparing performance on a neutral and an incongruent task, and increases in facilitation between a neutral and congruent task, suggesting that people struggle more in applying attentional and inhibitory control as they age (Spieler, Balota & Faust, 1996). The dorsolateral prefrontal cortex appears to be less responsive with age, which results in irrelevant information being processed for longer than that of younger adults (Milham et al., 2002). Reading also uses specific language structures.

Language is one cognitive domain that is commonly lateralized to the left hemisphere. As the Stroop task is a language-based task, it would be expected that a Stroop task also requires more input from the left hemisphere than the right hemisphere. A study conducted by Bernal and Altman (2009) found that the Stroop task predominantly utilized left hemisphere structures in both males and females, with the greatest activation found in the left inferior frontal gyrus (Broca's area). Some previous studies have found that females tend to be more bilateral than males in language processing, and quicker overall at the Stroop task (Macleod, 1991; McGlone, 1977). However, a meta-analysis conducted by Belanger and Cimino (2002) failed to find sex differences in the degree of interference or lateralization between males and females. Furthermore, Belanger and Cimino (2002) failed to find evidence of left hemisphere lateralization for the Stroop task. More recent research has suggested that the absence of evidence for left hemisphere lateralisation in previous research may be due to these studies requiring a motor response (Bernal & Altman, 2009). Bernal and Altman found that when an overt motor response was not required, the Stroop task did appear to be a predominately left hemisphere task. They suggested that because motor inhibition predominately utilizes right hemisphere structures, previous research was misattributing activation of right hemisphere structures to the Stroop task. Despite this, the right hemisphere does play a role, with studies on priming suggesting that the right hemisphere is involved in storing and maintaining multiple words and their meanings, and is key for resolving lexical ambiguity, which is important for performing a Stroop task (Faust & Gernsbacher, 1996; Belanger & Cimino, 2002). Colour words are held for prolonged periods of time in the brains short-term storage during a Stroop task in order to be recalled quickly when necessary. Furthermore, resolving lexical ambiguity is paramount for successful completion of a Stroop task as quick decisions have to be made as to what colour is recalled. Because the Stroop task is relatively well understood, and has clear levels of difficulty, it is commonly used in multi-tasking research.

Stroop paradigm in dual-task research

Stroop tasks can be used in multi-tasking research, whereby the Stroop paradigm is one of two or more tasks performed concurrently. A study measuring the effects of a Stroop task when sitting, standing and walking found there was a significantly greater amount of Stroop errors when walking in comparison to sitting (Wollesen, Voelcker-Rehage,Regenbrecht & Mattes, 2016). It was also found that the Stroop task affected motor control, with evidence of greater sway length and velocity when standing, and reduced stride length when walking for the dual task condition compared to the single task condition (Wollesen et al., 2016). According to that study, walking uses more cognitive resources than sitting and standing, thus leaving fewer cognitive resources to perform the Stroop task. Differences in movement between Stroop conditions has also been studied.

A recent study conducted by Killeen and colleagues (2017) investigated the effects of a Stroop task on left and right arm swing symmetry in three groups of participants: young, middle-age, and older. They measured arm swing trajectory in both arms while participants walked normally on a treadmill (control/single-task), completed a congruent Stroop task (easy dual-task) and completed an incongruent Stroop task (hard dual-task). For the older age group (60-80), males displayed increased asymmetry by decreasing right arm swing amplitude when presented with the incongruent task compared to the normal walking task and females did the same when presented with both the congruent and incongruent task compared to the normal walking task. These results were similar to those for the males in the other two age groups. Males in the middle age group (40-59) showed significantly larger asymmetry for the normal walking task compared to both Stroop tasks and males in the youngest age group (18-29) showed significantly larger asymmetry for the incongruent task compared to the control condition. In contrast, females aged 18-40 showed no significant asymmetry changes. Killeen and colleagues (2017) suggested these results occurred because the Stroop task primarily utilizes left-hemisphere structures, which reduces the remaining resources of the left-hemisphere. Movements on the right-hand side of the body, which require the left-hemisphere, are subject to more interference by the Stroop task than movements on the ipsilateral side. However, younger males' asymmetry increase was driven by an increase in left arm swing amplitude rather than in decreased right arm swing amplitude, which is not consistent with this interpretation of the results. Despite this, Killeen and colleagues (2017) suggested younger women might be less impacted by interference because they have greater levels of oestrogen in the brain, which is implicated in cognitive control and cognitive control tasks, such as the Stroop task (Luine, 2014). Killeen and colleagues (2017) suggested this is evidence that younger females have better multi-tasking abilities than males and older females.

While the method used by Killeen and colleagues found Stroop effects on arm symmetry embedded in locomotion, these kinds of movements are well practiced and largely automatic. Research has tended to find that cognitive tasks cause bilateral effects on locomotion, as symmetry is necessary for smooth coordinated movements (Al Yahyah et al., 2011: Killeen et al., 2017). Tasks utilizing the upper limbs, but not embedded in locomotion may result in greater interference and possibly a greater increase in asymmetry. Simple movements involving the hands may be used to test this hypothesis.

Bimanual coordination

The complex, goal-directed movements humans can make are part of what sets them apart from other species. Through evolution, humans have moved into an upright stance, whereby the upper limbs have become increasingly functional and can perform a huge variety of complex actions (Swinnen, 2002, Swinnen & Wenderoth, 2004). These complex actions performed by the upper limbs are known as bimanual coordination tasks, and allow humans to perform synchronized actions like swimming and rowing, and fine motor movements like eating with a knife and fork (Swinnen, 2002). Simple and complex bimanual coordination tasks are common in research requiring the integration of both upper limbs simultaneously (Swinnen & Wenderoth, 2004).

Commonly used bimanual coordination tasks are in-phase and anti-phase movements. In-phase movements are those where the limbs move in mirror symmetry whereas anti-phase movements are 180 degrees out of phase and move in parallel (Salter, Wishart, Lee & Simon, 2004). Research suggests that anti-phase movements are less stable than in-phase movements because they use non-homologous muscle groups simultaneously (Carson, Riek, Smethurst, Parraga & Byblow, 2000; Salter et al., 2004). However, more conclusive research found that the preference to move upper limbs in mirror symmetry is because of the preference for spatial and perceptual symmetry (Mechsner, Kerzel, Knoblich & Prinz, 2001). Based on the preference for in-phase movements, it is common for movement to switch from being in anti-phase to in-phase, but not vice versa (Mechser et al., 2001;

Swinnen, 2002). The ability of the brain to successfully perform these kinds of movements appears to be dependent on specific regions.

Bimanual coordination requires activation of numerous parts of the brain to be performed successfully. Movement on each side of the body is controlled by the contralateral hemisphere, with both hemispheres involved in coordinating the movements cohesively (Viviana et al., 1998). A study conducted by Swinnen and Wenderoth (2004) suggested that there is a general sensorimotor network of areas that show consistent activation including the primary motor cortex, premotor cortex, supplementary motor areas and the cerebellum and that this network is involved in both in-phase and anti-phase movements. More recent research has also highlighted the importance of the corpus callosum in bimanual coordination, specifically in integrating information between the two hemispheres (Gooijers & Swinnen, 2014). Research has found that the ability of the brain to successfully initiate bimanual coordination movements, particularly anti-phase movements is greatly affected by task complexity and dual task conditions.

Bimanual coordination in dual-task research

Similar to general multi-tasking, performance of a bimanual coordination task hinders ability to simultaneously perform a second task. Research has suggested that humans have great difficulty in performing two different tasks with each hand simultaneously and that difficulty increases as the two tasks become more complex (Oliveira & Ivry, 2008). This is because the connections between the two hemispheres of the brain results in a lack of independence between the hands (Oliveira & Ivry, 2008). Similar findings are evident in studies measuring the effects of simultaneously performing a bimanual coordination task and a secondary cognitive task. A study conducted by Ridderikhoff, Peper and Beek (2008) found that reaction times on a cognitive task were always larger when performed with a bimanual coordination task compared to when performed in isolation, or if the coordination patter was anti-phase compared to in-phase. Another study conducted by Matthews, Martin, Garry and Summers (2009) found that accuracy on a difficult visual task was greater when performed with an in-phase pattern compared to an anti-phase pattern. These results suggest that the performance of a bimanual coordination tasks requires significant cognitive resources, which can hinder performance on a second cognitive task, particularly when performed in anti-phase.

Present Study

The previously outlined research on multi-tasking has provided consensus that multi-tasking has detrimental consequences on the performance of either or both tasks (Al Yah Yah et al., 2011; Bowman et al., 2010; Killeen et al., 2017; Stoet et al., 2011). The consequences of multi-tasking become even greater as people get older, with both males and females showing greater difficulty in performing more than one task over age 40 (Killeen et al., 2017). Furthermore, a recent study conducted by Killeen and colleagues (2017) has suggested evidence for better multi-tasking abilities in females, whereby arm swing while walking was disturbed by a difficult Stroop task for young males but not for young females. However, arm movements are embedded in walking and such an automatic movement pattern is likely to be effected minimally by a cognitive task. Therefore, multi-tasking involving a less automatic movement task may demonstrate more detrimental effects.

The present study seeks to measure the effects of a Stroop task on a movement task. The present study focuses on the use of anti-phase movements of the upper limbs, as these are similar, in the sense of the coordination pattern, to the movements made by the upper limbs when walking. However, because such movements are not embedded in locomotion, and considered less stable than in-phase movements, it is expected that movement will be more affected by increasing cognitive load with a Stroop task.

Consistent with evidence from previous multi-tasking research, it is expected that there will be detrimental consequences on the bimanual coordination task as the Stroop difficulty increases. Specifically, it is hypothesised that amplitude will decrease between the congruent Stroop condition and the control condition, and decrease again in the incongruent Stroop condition. It is also hypothesised that frequency will decrease between the congruent Stroop condition and the control condition, and decrease again in the incongruent Stroop condition.

Consistent with the results found by Killeen and colleagues (2017), the present study seeks to find differences between males and females in their ability to simultaneously perform both tasks. It is hypothesised that males will show significant increases in asymmetry on the bimanual lever task when presented with the incongruent Stroop condition compared to the control condition. It is also hypothesised that females will not show any significant differences in asymmetry on the bimanual lever task between the control, congruent and incongruent conditions.

Method

Participants

41 participants (21 females) were recruited between the ages of 18-40. One female was excluded from the final results due to obtaining a considerably greater mean number of Stroop errors in the incongruent condition compared to the rest of the sample (26.50 compared to 2.68). Demographic information is presented in Table 1. First year psychology students were granted 1 course credit for participation and other participants went into a draw to win one of three $50 Coles/Myer vouchers.

Participants were required to speak English as their first language and were excluded for colour blindness, reading disorders such as dyslexia, and known neuromuscular or neurological disorders. In addition, females were excluded if they had an irregular menstrual cycle, used the contraceptive Implanon, or were pregnant.

Table 1.

Participant Descriptive Statistics

Sex	Number	Mean Age	Mean Handedness
Male	20	24.50 (3.29)	0.19 (0.62)
Female	20	24.40 (4.82)	0.63 (0.35)

Note: Standard deviations are presented in parenthesis beside mean age and mean handedness

Independent samples t-tests revealed that there were no statistically significant differences in age between males and females, t (38) = -0.08, p = .939, 95% CI [-2.74, 2.54], d = 0.02. However, females were significantly more right dominant in their hand preference than males, t (29.94) = 2.79, p = .009, 95% CI [0.20, 0.77], d = 0.88.

Apparatus/materials

Edinburgh Handedness Inventory: The Edinburgh Handedness Inventory assesses hand preference for various everyday tasks such a writing, throwing and holding a knife. A score of zero indicates no hand preference whatsoever, a score below zero indicates greater left-hand preference whereas a score above zero indicates greater right-hand preference.

Bimanual coordination task: The bimanual coordination task was conducted using a desk with two identical levers, positioned roughly shoulder width apart. Participants sat in a height adjustable chair, which they were able to set to a comfortable position. The levers consisted of a cylinder-shaped base, positioned parallel to the desk surface and attached perpendicularly at one end to a potentiometer mounted below the desk surface. The levers also had a second vertical handle attached perpendicular to the first. Participants grasped the vertical handle such that wrist joints were positioned directly above, and coaxial with, the axis of rotation. The hands were in a neutral position with the thumbs up and palms facing inward. The thumb and forefinger held the vertical portion of the levers, and other fingers were extended with the little finger resting against the outside edge of the base lever. This provided stable contact with the levers and ensured the hand and lever moved as a single unit. The position of the levers was recorded at a rate of 1000 Hz using a Cambridge Electronics Design 1401 Plus Analog to Digital Converter and Signal 4.0 software.

Stroop task: The Stroop task was adopted from that used by Killeen and colleagues (2017) and modified slightly for the purposes of the current research. The Stroop task consisted of three conditions: control, congruent and incongruent, which were all presented on a black 17-inch computer screen. In the control condition, a white cross was flashed on the screen. In the congruent condition, the colour words were presented in the same ink colour (e.g., the word 'Red' written in red ink). In the incongruent condition, the colour words were presented in a different ink colour (e.g., the word 'Red' written in blue ink). The following colour words and ink colours were used: red, blue, yellow, green, purple and orange. This included two more colours (yellow and purple) than the study by Killeen and colleagues in order to increase Stroop variability. In both Stroop conditions, no two sequential words were presented in the same ink colour. This is different to the method used by Killeen and colleagues (2017) who only organized incongruent Stroop stimuli to not be consecutively presented in the same ink colour. The Stroop stimuli were presented for a duration of 500ms with a mean inter-stimulus interval (ISI) of 1000ms, that varied between 600ms and 1400ms for individual stimuli.

Procedure

To begin with, information sheets and consent forms were provided and completed. After consent had been obtained, participants completed the Edinburgh Handedness Inventory. Participants were then instructed and shown how to correctly hold the levers for performing the bimanual coordination task. Once in the correct position, participants were instructed to move the levers in an anti-phase manner, consistent with a comfortable flexion, extension of the wrist at a speed around 1 Hz. Once the bimanual coordination task was understood, participants were informed of the Stroop task. Participants were told that the word 'Ready' would flash up on the screen, informing them to begin the bimanual coordination task. Once participants began moving, words (congruent and incongruent conditions) or a white cross (control condition) were presented on the computer screen. Participants were instructed to say the colour of the text the word was written in. This differs from the study of Killeen and colleagues (2017) who instructed their participants to say the word *silently* in their head while verbalizing the colour.

Once both tasks were understood, participants were given four, 30 second test trials, consisting of two congruent and two incongruent Stroop conditions. Each practice trial was followed by a one-minute break. The 60 second practice trial time used by Killeen and colleagues (2016) was reduced to 30 seconds in the present study, and incongruent test trials were added to ensure participants understood this condition prior to beginning the real test trials. Once the practice trials were completed, participants were given a two-minute break before commencing the test trials.

In total, there were 24 test trials, broken into four, six-trial blocks. This resulted in a total of eight trials of each condition, which is an increase in the number of trials used by Killeen and colleagues (2017) who only presented four trials for each condition. The three Stroop conditions were counterbalanced, so that the order differed between blocks and between participants. Each six-trial block consisted of two consecutive control conditions, two consecutive congruent conditions and two consecutive incongruent conditions, but this order was counterbalanced between blocks and participants. This was also different to the method used by Killeen and colleagues (2017) who presented trials in a set order of control, then congruent, and finally incongruent. The present study counterbalanced the conditions to ensure that study effects such as fatigue and concentration impacted the conditions similarly. Each trial was 60 seconds, with a one-minute break in-between. After each six-trial block, participants were given a longer, two-minute break. Incorrect responses were recorded manually and a camera was positioned facing the computer screen in order to cross reference incorrect responses. Once all trials were completed, participants were thanked for their participation and given the opportunity to rest before leaving.

Movement analysis

The lever movements were low-pass filtered using a 10 Hz Butterworth filter. A custom algorithm programmed in Signal 4.0 was used to locate the points of peak wrist flexion and peak wrist extension for each flexion-extension cycle during the trials.

Movement amplitude (arbitrary units), was calculated as the distance traveled between one flexion peak and the following peak extension, and vice versa for all movement cycles within each trial. To eliminate potential positioning or movement errors at the start and end of each trial, the mean amplitude was calculated from the movement cycles in the middle 55 seconds of every trial. The mean amplitude for a condition was calculated as the grand mean of all eight trials for that condition.

Movement frequency (Hz) was calculated as the reciprocal of the time (in seconds) between two adjacent wrist extension peaks (the start and end of each full movement cycle). The mean frequency was calculated from the movement cycles in the middle 55 seconds of every trial. The mean frequency for each condition was calculated as the grand mean of all eight trials for that condition.

To ensure that participants had performed the required coordination pattern (anti-phase), continuous relative phase and standard deviation of relative phase were calculated for every trial. To calculate relative phase, each movement cycle (extension-flexion-extension) is scaled to a movement of 360 degrees. Therefore, the values reflect the phase position of the hand within each cycle, rather than the physical position of the hand. At peak extension, the hand is at 0 degrees and wrist flexion moves the hand toward peak flexion, which is 180 degrees, or halfway through its cycle. As the wrist extends it advances from 180 degrees to 360 degrees, which is the phase position of the following peak extension. This transformation is performed for every extension-flexion-extension cycle for both hands. By subtracting the phase position of one hand from the phase position of the other hand for each point in time, the relative phase of the hands is obtained.

Relative phase values for amplitude and frequency were calculated for all points in the middle 55 seconds of each trial. The mean of those relative phase (mean RP) values provides an estimate of the phase relationship of the hands within a trial. The standard deviation of relative phase (SD RP) provides an estimate of how consistent participants were in maintaining that phase relationship, with 0 degrees representing perfect synchronisation. In the current study the required relative phase was 180 degrees (i.e., one hand is at peak flexion when the other is at peak extension). Relative phase was obtained by subtracting the right hand's phase position from the left hand's phase position with the result that mean RP greater than 180 degrees indicates the left hand is leading and values less than 180 degrees indicate the right hand is leading.

Analysis

The present study used a 2x2x3 factorial design. The first (between-subjects) independent variable was sex with two levels: male and female. The second (within-subjects) independent variable was hand with two levels: left and right. The third (within-subjects) independent variable was Stroop task with three levels: control, congruent and incongruent. When included in the analysis, sex was a level one factor, condition and hand were level one, repeated variables, and participants was the level two factor. The dependent variables were movement frequency measured in Hertz, movement amplitude measured in arbitrary units, Stroop errors, signed asymmetry and absolute asymmetry. Directional left/right symmetry was measured using the asymmetry index (ASI), which uses the formula ASI = [(mean left –mean right) / (max (left, right))] x 100. This gives values of -100 to 100, with -100 representing maximum right-dominant asymmetry and 100 representing maximum left-dominant asymmetry.

Results

Results were analysed using a mixed linear model analysis. All analyses were conducted twice using maximum likelihood estimation to determine the best fitting model using compound symmetry and unstructured covariance structures. Model fit is represented by a Chi-square likelihood ratio test (-2LL), where a smaller number reflects better fit. To compare the fit of the two models, the Schwarz's Bayesian criterion (BIC), which adjusts the likelihood based on the number of parameters and subjects, and the Chi-square statistics were compared across the two covariance structures. Despite being the simpler model, the compound symmetry covariance structure modeled the data better than the unstructured covariance structure in all analyses except the Stroop error and relative phase analyses.

Relative phase

Relative phase was analysed using a 2 (Sex) by 2 (Condition) Mixed Linear Model. Descriptive statistics are displayed in Table 2. Comparing the model using Unstructured (-2LL = 661.063, 12 parameters) and Compound Symmetry (-2LL = 682.160, 8 parameters) covariance structures for the repeated factor revealed that the model using the Unstructured covariance structure was a significantly better fit for the model, $\chi(4) = 21.10$, $p < .001$. After adjusting each model for complexity, the Unstructured (BIC = 718.51) covariance structure was still better than the Compound Symmetry (BIC = 720.46) covariance structure. Therefore, the Unstructured model was used to interpret relative phase. There were no significant main effects of Sex, F (1, 40) = 2.46, $p = .125$ or condition, F (1, 40) = 0.12, $p = .887$. There was also no significant interaction between sex and condition, F (2, 40) = 0.72, $p = .483$.

Standard deviation of relative phase

SD RP was analysed using a 2 (Sex) by 2 (Condition) Mixed Linear Model. Descriptive statistics are displayed in Table 3. Comparing the model using Unstructured (-2LL = 595.12, 12 parameters) and Compound Symmetry (-2LL = 600.55, 8 parameters) covariance structures for the repeated factor revealed that while the model using the Compound Symmetry covariance structure was a slightly worse fit, the difference between models was not statistically significant, $\chi(4) = 5.44$, $p = .246$. Furthermore, after adjusting each model for complexity, the Compound

Symmetry (BIC = 638.85) covariance structure was better than the Unstructured (BIC = 652.57) covariance structure. Therefore, the Compound Symmetry model was used to interpret SD RP.

Table 2.

Descriptive statistics for relative phase

	Control	Congruent	Incongruent
Females			
Mean	176.43 (SD = 6.97)	175.92 (SD = 7.70)	176.19 (SD = 7.75)
95% CI	[173.17, 179.69]	[172.32, 179.52]	[172.56, 179.82]
Males			
Mean	178.74 (SD = 4.93)	179.16 (SD = 5.27)	179.50 (SD = 5.78)
95% CI	[176.43, 181.05]	[176.70, 181.63]	[176.80, 182.20]

Table 3.

Descriptive statistics for SD RP

	Control	Congruent	Incongruent
Females			
Mean	11.90 (SD = 3.00)	12.53 (SD = 3.42)	13.38 (SD = 3.56)
95% CI	[10.50 13.30]	[10.93, 14.13]	[11.71, 15.05]
Males			
Mean	12.46 (SD = 6.64)	12.72 (SD = 6.43)	14.07 (SD = 7.43)
95% CI	[9.35, 15.58]	[9.71, 15.72]	[10.59, 17.54]

There was a significant main effect of Condition, F (2, 80) = 8.57, p<.001, with the control condition having the smallest standard deviation, followed by the congruent condition, and then the incongruent condition. Pairwise comparisons revealed that the incongruent condition had a significantly larger standard deviation compared to both the control condition (*p* <.001, *d* = 0.29) and the congruent condition (*p* = .005, *d* = 0.20). There was no main effect of Sex, *F* (1, 40) = 0.09, *p* = .768. There was also no interaction between Sex and Condition, *F* (2, 80) = 0.23, *p* = .794.

Stroop Errors

Stroop errors were calculated by averaging the number of errors across all eight trials in each of the Stroop conditions (congruent and incongruent). This data was analysed using a 2 (Sex) x 2 (Condition) Mixed Linear Model. Comparing the model using Unstructured (-2LL = 144.61, 7 parameters) and Compound Symmetry (-2LL = 291.03, 6 parameters) covariance structures for the repeated factor revealed that the model using the Unstructured covariance structure was a significantly better fit for the model, $\chi(1) = 146.45$, p<.001. Furthermore, after adjusting each model for complexity, the Unstructured (BIC = 175.28) covariance structure was still better than the Compound Symmetry (BIC = 317.32) covariance structure. Therefore, the Unstructured model was used to interpret Stroop error results.

Females had a mean error rate of 0.05 (SD = 0.09, 95% CI [0.01, 0.09]) in the congruent condition and 2.58 (SD = 2.19, 95% CI [1.56, 3.61]) in the incongruent condition. Males had a mean error rate of 0.13 (SD = 0.23, 95% CI [0.02, 0.24]) in the congruent condition and 2.78 (SD = 2.13, 95% CI [1.79, 3.78]) in the incongruent condition. For both males and females, there was a significantly larger number of Stroop errors made in the incongruent condition compared to the congruent condition *F* (1, 40) = 62.62, *p* <.001, 95% CI [1.93, 3.25], *d* = 1.71. This had a very large effect size. There were no differences in Stroop errors between males and females, *F* (1,

40) = .171, *p* = .681, 95% CI [-0.55, 0.83], *d* = 0.13. This had a very small effect size.

Frequency

Frequency was analysed using a 2 (Sex) x 2 (Hand) x 3 (Condition) Mixed Linear Model. Descriptive statistics are displayed in Table 4. The model fit statistic was -2LL = -446.21 with 14 parameters. There was a significant main effect of Condition, *F* (2, 200) = 119.25, *p* <.001, with the control condition having the smallest frequency, followed by the congruent condition and then the incongruent condition. Pairwise comparisons revealed that all three conditions differed significantly from each other at an alpha level of *p* <.001. This difference had a small effect for the control condition compared to both the congruent (*d* = 0.20) and the incongruent (*d* = 0.36) conditions. Despite the difference between congruent and incongruent being significant, this had a very small effect size (*d* = 0.16). There were no significant main effects of Hand, *F* (1, 200) = 0.05, *p* = .822, or Sex, *F* (1, 40) = 0.40, *p* = .531.

While there was a significant main effect of Condition, there was also a significant interaction between Sex and Condition, suggesting that the relationship between frequency and Condition differed for males and females, *F* (2, 200) = 4.54, *p* = .012 (see figure 1). This interaction was followed up with post-hoc 2 (Sex) x 2 (Hand) x 2 (Condition) Mixed Linear Models, excluding one Stroop condition in each analysis and interpreting only the Sex by Condition interactions. There were significant interactions between Sex and Condition in the control and incongruent conditions (-2LL = -205.70 with ten parameters, *F* (1, 120) = 4.12, *p* = .045) and the congruent and incongruent conditions (-2LL = -352.74 with ten parameters, *F* (1, 120) = 20.65, *p* <.001), but not in the control and congruent conditions (-2LL =

268.75 with ten parameters, F (1,120) = 0.281, p = .597). The difference between the control and incongruent conditions was small for both males and females (males d = 0.36; females d = 0.37), with females having a slightly larger effect despite having a smaller difference due to smaller standard deviations. The difference between the congruent and incongruent conditions was small for males (d = 0.19), and very small for females (d = 0.12). These results indicate a tendency for movement frequency to increase as Stroop difficulty increased, but females demonstrated a smaller increase between congruent and incongruent than males.

Table 4.

Descriptive statistics for frequency

	Control	Congruent	Incongruent
Females (left hand)			
Mean	1.30 (SD = 0.33)	1.38 (SD = 0.32)	1.42 (SD = 0.34)
95% CI	[1.15, 1.45]	[1.23, 1.53]	[1.27, 1.58]
Females (right hand)			
Mean	1.30 (SD = 0.33)	1.38 (SD = 0.32)	1.42 (SD = 0.37)
95% CI	[1.14, 1.45]	[1.23, 1.53]	[1.26, 1.58]
Males (left hand)			
Mean	1.36 (SD = 0.44)	1.44 (SD = 0.47)	1.53 (SD = 0.50)
95% CI	[1.16, 1.57]	[1.22, 1.66]	-1.30, 1.76]
Males (right hand)			
Mean	1.37 (SD = 0.45)	1.44 (SD = 0.48)	1.54 (SD = 0.50)
95% CI	[1.16, 1.58]	[1.22, 1.67]	[1.30. 1.77]

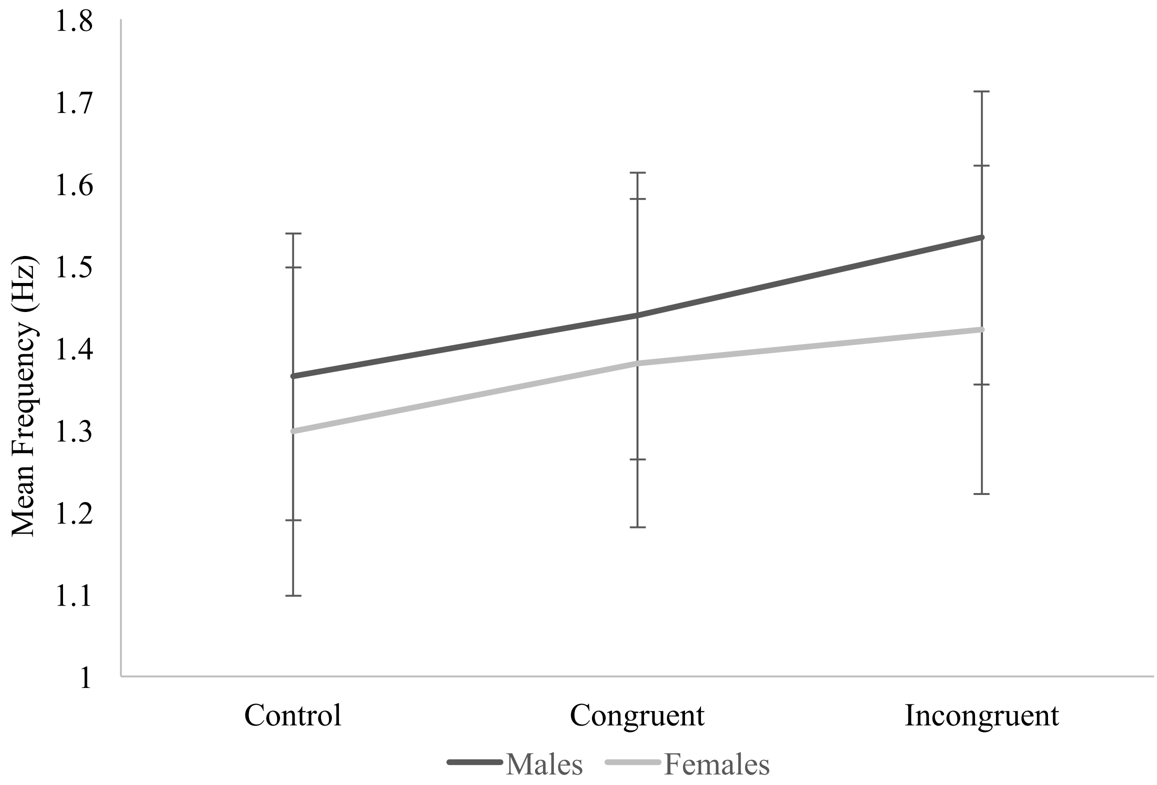

Figure 1. Mean frequency of males and females in the control, congruent and incongruent conditions. Error bars represent 95% Confidence Intervals.

Amplitude

Amplitude was analysed in the same way as frequency, using a 2 (Sex) x 2 (Hand) x 3 (Condition) Mixed Linear Model. Descriptive statistics are displayed in Table 5. The model had a -2LL of -424.71 with 14 parameters. There was a significant main effect of Condition, F (2, 200) = 7.71, p = .001. Pairwise comparisons revealed that hand movement amplitude in the control condition was significantly larger than in the congruent condition (p = .002, d = 0.13) and the incongruent condition (p<.001, d = 0.16), with both comparisons having very small to small effect sizes. Hand movement amplitude in the congruent condition was non-significantly smaller to hand movement amplitude in the incongruent condition (p = .611, d = 0.02). There were no significant main effects of Hand, F (1, 200) = 0.02, p = .897, or Sex, F (1, 40) = 1.37, p = .250.

Table 5.

Descriptive statistics for amplitude

	Control	Congruent	Incongruent
Females (left hand)			
Mean	1.01 (SD = 0.28)	0.97 (SD = 0.29)	0.97 (SD = 0.25)
95% CI	[0.88, 1.14]	[0.83, 1.10]	[0.85, 1.09]
Females (right hand)			
Mean	0.98 (SD = 0.26)	0.95 (SD = 26)	0.96 (SD = 0.25)
95% CI	[0.86, 1.11]	[0.83, 1.07]	[0.84, 1.07]
Males (left hand)			
Mean	0.90 (SD = 0.26)	0.87 (SD = 0.24)	0.85 (SD = 22)
95% CI	[0.78, 1.02]	[0.76, 0.98]	[0.75, 0.96]
Males (right hand)			
Mean	0.92 (SD = 0.29)	0.89 (SD = 0.26)	0.87 (SD = 0.25)
95% CI	[0.79, 1.05]	[0.76, 1.09]	[0.75, 0.98]

Despite no main effect of hand or sex, there was a significant interaction between the two, F (1, 200) = 4.00, p = .047, suggesting that the difference in movement amplitude for the left and right hand differed between males and females. This interaction indicated that overall, females had greater amplitude with the left hand compared to the right hand (d = 0.07) whereas males had greater amplitude with the right hand compared to the left hand (d = 0.07). However, both of these had trivial effect sizes. This relationship is displayed in Figure 2.

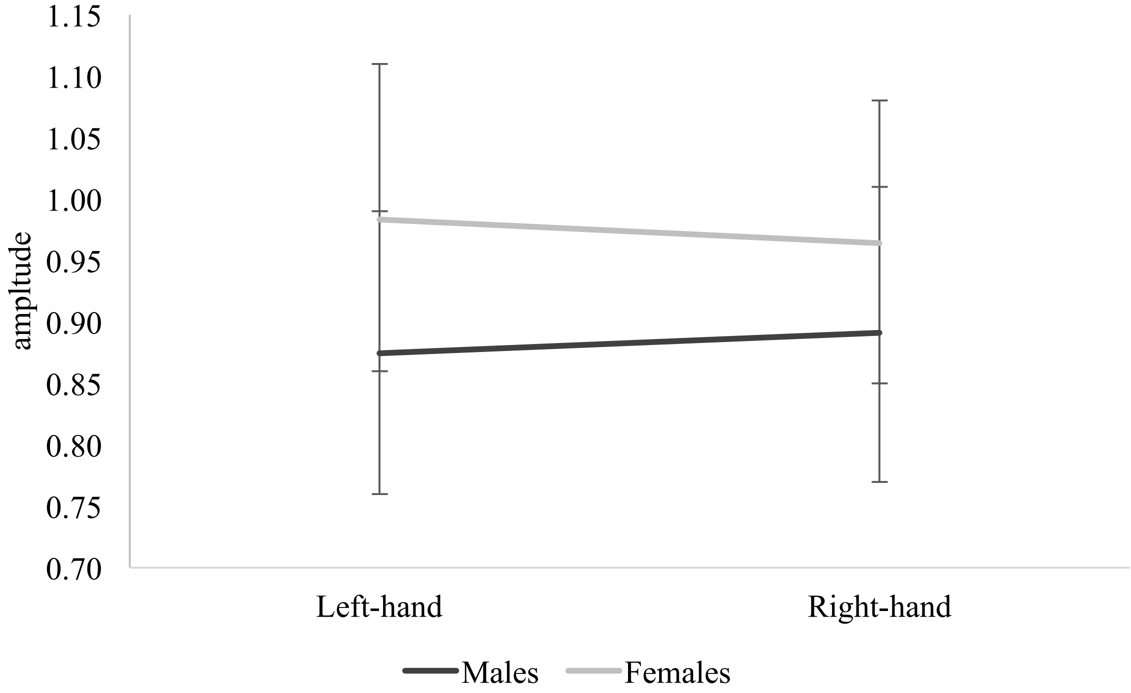

Figure 2. Mean amplitude of the left and right hand for males and females. Error bars represent 95% Confidence Intervals.

Asymmetry Index

ASI was analysed using a 2 (Sex) by 3 (Condition) Mixed Linear Model. Descriptive statistics are displayed in Table 6. The model had a -2LL of 715.50 with eight parameters. While males tended to have larger movements on the left and females tended to have larger movements on the right, there were no significant main effects of sex, F (1, 40) = 1.26, p = .268, or condition, F (2, 80) = 0.36, p = .699. There was also no significant interaction between sex and condition, F (2, 80) = 0.95, p = .393.

Absolute (unsigned) symmetry was also analysed, with larger values representing greater asymmetry. This was included to test whether magnitude of ASI, ignoring directional bias, differed for males or females. Descriptive statistics are displayed in Table 7. The model had a -2LL of 676.74 with eight parameters.

There were no significant main effects of Sex, F(1, 40) = 0.32, p = .576, or Condition, F (2, 80) = 1.90, p = .156. There was also no significant interaction between Sex and Condition, F (2, 80) = 0.62, p = .541.

Table 6.

Descriptive statistics for ASI

	Control	Congruent	Incongruent
Females			
Mean	2.11 (SD = 7.74)	1.14 (SD = 9.69)	1.39 (SD = 9.57)
95% CI	[-1.51, 5.73]	[-3.39, 5.67]	[-3.09, 5.87]
Males			
Mean	-1.81 (SD = 8.52)	-1.62 (SD = 8.17)	-0.89 (SD = 9.68)
95% CI	[-5.79, 2.18]	[-5.45, 2.20]	[-5.42, 3.63]

Table 7. Descriptive statistics for absolute symmetry

	Control	Congruent	Incongruent
Females			
Mean	5.79 (SD = 5.41)	6.98 (SD = 6.63)	7.18 (SD = 6.27)
95% CI	[3.26, 8.32]	[3.87, 10.08]	[4.25, 10.12]
Males			
Mean	7.25 (SD = 4.54)	7.17 (SD = 3.92)	8.10 (SD = 5.04)
95% CI	[5.13, 9.38]	[5.33, 9.01]	[5.74, 10.46]

Discussion

The present study primarily aimed to investigate sex differences in multi-tasking, using the Stroop paradigm and a bimanual coordination task. Results and conclusions regarding each hypothesis will be discussed in the following section.

Relative phase

The relative phase analysis provided information on accuracy of the anti-phase pattern in the bimanual coordination task. For the relative phase, performance was very good and did not deviate between Stroop conditions. This provides evidence that participants were completing the anti-phase movement as instructed. For the standard deviation of relative phase, participants were relatively good at maintaining the anti-phase relationship. However, the significant main effect of condition suggests that anti-phase stability did suffer as Stroop difficulty increased, but these differences had a small effect size. Furthermore, there were no differences between males and females.

Amplitude and frequency differences

The present study hypothesised that for both males and females, hand movement amplitude would decrease as Stroop difficulty increased. Research has found that this tends to be the case in dual-task circumstances, where each task competing for resources leads to a decrease in performance (Al-Yahya, 2011; Killeen et al., 2017). This hypothesis was partially supported. There was a significant, though of small effect size, decrease in amplitude between the control condition and both the congruent and incongruent conditions. While there was a slight decrease in amplitude from the congruent condition to the incongruent condition, this decrease was not significant and the effect size was trivial. This suggests that when the task switched from being a single-task to a dual-task, there were consequences for the bimanual coordination task. However, when the task went from being an easy dual-task to a difficult dual-task, there were no significant further effects for amplitude.

It was hypothesised that hand movement frequency on the bimanual coordination task would decrease as Stroop difficulty increased, in line with previous research where task completion time and efficiency decreased in dual-task situations (Watson & Strayer, 2010; Redick et al., 2012; Stoet et al., 2013). This hypothesis was not supported and surprisingly the opposite effect was found. Though the effect sizes were small, for both males and females, frequency *increased* from the control condition to the congruent condition, and increased further from the congruent condition to the incongruent condition. However, this effect interacted with sex. While males and females both increased in frequency as Stroop difficulty increased, females increased less between the congruent and incongruent conditions than males did. This suggests that males and females are similarly affected when changing from a single-task to a dual-task condition, but males are affected more when performing a difficult dual-task condition. This may not be evidence that females are better at multi-tasking than males per se, but it does provide some support that females have an advantage over males that manifested in more stable movement. However, it was hypothesised that frequency would *decrease* as Stroop difficulty increased, and this finding is clearly inconsistent with that. The lack of full independence between movement amplitude and frequency may have contributed to this finding.

Frequency and amplitude are two movement constraints that are coupled closely together. Research has found that movement amplitude and frequency naturally have an inverse relationship whereby as amplitude decreases, frequency increases (Bosga-Stork, Bosga & Meulenbroek, 2014; Zawadzki and Siemienski, 2010). Zawadzki and Siemienski (2010) suggested that as someone runs faster (movement frequency), they naturally begin to decrease their stride length (movement amplitude). Therefore, it is likely that this was the case in the bimanual coordination task used in the present study, making it very unlikely that both movement amplitude and frequency would decrease together. Dual-task research in walking has shown the tendency for movement amplitude to decrease from a single-task condition to a dual-task condition, therefore it is likely that this occurred in the present task and frequency increased as a result (Wollesen et al., 2016). These hypotheses mainly concerned general multi-tasking tendencies, but the results indicated some evidence for sex differences in movement frequency. The remaining hypotheses specifically related to sex differences in line with the results of Killeen and colleagues (2017).

Asymmetry differences

The main hypothesis in the current study was that males would become more asymmetrical on the bimanual coordination task as Stroop difficulty increased. This hypothesis was not supported. There were no significant differences in directional asymmetry between Stroop conditions for males. Based on the means, there appears to be a tendency for males to be the most asymmetrical in the control condition, followed by the congruent condition and then the incongruent condition. However, this is in contrast to Killeen and colleagues (2017) results, as male's asymmetry in the present study was defined by larger amplitude on the left, which became more symmetrical as Stroop difficulty increased, therefore reducing the ratio of left amplitude in relation to right. Killeen and colleagues (2017) results had the opposite tendency; males became more asymmetrical as Stroop difficulty increased, defined by increasing the ratio of left amplitude in relation to right. Therefore, the present study failed to find evidence that males suffered consequences to movement on the right as expected if left hemisphere resources were increasingly used by the Stroop task. Furthermore, the conclussions Killeen and colleagues (2017) derived did not sufficiently follow from the results they found.

While Killeen and colleagues (2017) found that males became more asymmetrical as Stroop difficulty increased, their conclusion did not directly reflect their results. As previously discussed, Killeen and colleagues suggested that because the Stroop task uses left hemisphere structures, there are fewer resources available for initiating and performing movements on the right-hand side of the body which are also controlled by the left hemisphere. Because of this, arm swing on the right-hand side of the body was reduced whereas arm swing on the left-hand side of the body was not. However, in the youngest age group, males' asymmetry increase was driven by an increase in *left* arm swing rather than a decrease in right arm swing. Therefore, the idea that the Stroop task reduced the amount of available resources left for right-hand side movement appears to be inconsistent with their results (despite the increased asymmetry overall). Furthermore, in this age group, males only showed asymmetry differences between the control and incongruent Stroop conditions, which only just reached significance (p = .048). The slightly larger sample used in the present study, as well as the inclusion of more trials is likely to have increased the validity of results.

The finding that movement asymmetry was not affected by the tasks was also seen in absolute asymmetry. In contrast to directional asymmetry, this measure does not differentiate between left or right dominant asymmetry, but provides a more general measure of asymmetry, with larger values representing greater asymmetry. While the majority of people are estimated to have language structures predominately in the left hemisphere, the remaining one in nine may show the opposite tendency, which could skew results (Carey & Johnstone, 2014). By including a measure of absolute asymmetry, this issue is eliminated as it does not matter if the asymmetry is driven by larger movements on the right or left-hand side.

Despite this, the hypothesis that males would become more asymmetrical as Stroop difficulty increased was not supported. Instead, males did not show a clear pattern in either direction. Therefore, the present study has found no evidence in support of males becoming more asymmetrical in their movements between performing a single task (control condition) and an easy dual-task condition (congruent) or a hard dual-task condition (incongruent). If anything, the directional and absolute asymmetry measures have indicated a tendency for males to become slightly more symmetrical, or to show no clear differences in either direction, respectively.

Based on the results by Killeen and colleagues (2017) the present study hypothesised that females would not show any significant differences in asymmetry between any of the Stroop conditions. This hypothesis was supported by the results of both asymmetry measures. As indicated by the directional asymmetry measure, females did not show any clear directional differences across the three Stroop conditions. In the absolute asymmetry measure, females showed a tendency to increase in asymmetry as Stroop difficulty increased, but neither of these differences approached significance. Therefore, females performed very similarly to males in terms of asymmetry, showing no significant tendency to increase or decrease in asymmetry as Stroop difficulty increased.

Stroop differences

The level of difficulty experienced by males and females in performing a Stroop task is an area of controversy in the literature (McGlone, 1977; Belanger and Cimino, 2002). The present study found no significant differences between males and females on Stroop task performance. There was an overall increase in errors from the congruent condition to the incongruent condition and this difference had a very large effect. While males had a slightly larger amount of Stroop errors than females, this difference was not close to reaching significance and had a very small effect size. Therefore, the current study found no evidence that females were better at performing the Stroop task than males. Despite this, other Stroop factors may impact on dual-task results.

Stroop task as a language task

Killeen and colleagues (2017) proposed their results indicated that performance of a Stroop task leads to differential effects on each side of the body because it predominately relies on left hemisphere language structures. However, this conclusion is not entirely justifiable. The requirement for completing a Stroop task is to say the ink colour, rather than read the word. Therefore, if instructions were followed, the Stroop task would not be a language task at all. Despite this, it is common to merely read the word when congruent stimuli are grouped together, which would require activation of language structure (Notebaert and Soetens, 2006). However, when identifying incongruent stimuli, successful completion involves inhibiting the written word, therefore language is being inhibited rather than applied (Milham et al., 2002; Bernal & Altman, 2009). As such, left-hemisphere language structures should not be involved more than right-hemisphere structures in an incongruent trial. Killeen and colleagues (2017) found that the largest differences in arm swing in all age groups were between the control condition and the incongruent condition. While this indicates a switch from a single-task to a dual-task, it does not necessarily indicate a switch from a single-task to a dual-task involving language. However, Killeen and colleagues (2017) told participants to say the word silently in their head while verbalizing the ink colour. If participants followed these instructions, both of the Stroop conditions should have involved language processes and used the necessary structures. This instruction may have led to that study finding asymmetry increases whereas the present study did not.

Stroop task and other cognitive processes

While language systems may be involved in performance of the Stroop task, there are other important systems involved as well, which could impact dual-task paradigms. To perform a verbal Stroop task, a motor response is required for speech, which will have an effect on motor and Stroop performance (Bernal & Altman, 2009). However, this would have similar bilateral effects across movement and should not necessarily be an issue with this study or previous studies using similar paradigms. It is also expected that Stroop task performance will improve with practice (MacLeod, 1991). Despite this, in the study by Killeen and colleagues (2017) there were no incongruent practice trials given to participants. This could have negatively affected performance on the incongruent test trials because participants were required to see and perform an incongruent test trial with no practice, whereas they had four practice trials for the congruent condition. Therefore, better performance in the congruent condition could be due to practice effects. One reason that the present study did not find similarly large differences for the incongruent condition compared to the control and congruent conditions could have been merely because participants had the same amount of practice with both Stroop conditions.

Limitations and future directions

The present study aimed to semi-replicate the study conducted by Killeen and colleagues (2017) with minor alterations to the method aimed to improve the validity of research findings. Despite this, there were still some limitations of the present study. The choice of bimanual coordination task was possibly a bit too restrictive in that amplitude and frequency were tightly constrained to each other. This probably resulted in the tendency for changes in amplitude to create inverse changes in frequency, making the two somewhat naturally dependent on each other. Regardless of the constraints upon amplitude and frequency in the bimanual coordination task, the main hypotheses of interest were related to asymmetry differences between males and females and are unlikely to have been affected by the amplitude/frequency dependence. Therefore, the lack of independence was not directly related to the lack of sex differences in asymmetry found in the present study.

A second limitation may have been that in the present study participants were not told to say the word silently in their head while stating the ink colour. This instruction could have engaged the left-hemisphere language structures in the study by Killeen and colleagues (2017) and resulted in a greater right to left arm-swing ratio. Further research should investigate the neural activity associated with each method in order to determine if there are differences in the activation of language structures between the two. Additionally, further research should investigate the neural activity associated with congruent and incongruent conditions separately, allowing for the common strategy of reading the word in the congruent trial to be adopted. This would be worthwhile in determining the level of activation of language structures between the two conditions.

It has been suggested that the reason females might be more successful multi-taskers than males is because they have higher levels of oestrogen, which aids in cognition (Killeen et al., 2017). However, Luine (2014) suggested that oestrogen aids in performance of some cognitive tasks, but not others. Based on the research by Luine (2014), it is likely that females may be better at dual-task paradigms that are associated with greater oestrogen levels, but not necessarily all dual-tasks paradigms. Perhaps the Stroop task is one that does not provide an advantage to either sex.

Conclusion

In light of the present study, there does not appear to be strong and consistent evidence of sex differences in a dual-task paradigm involving a Stroop task and a movement task. While there has been recent suggestion that there were unilateral effects on movement as Stroop difficulty increased, the present study found no such evidence. This is in line with the majority of evidence in this field, which has suggested that despite a strong stereotype that females are better at multi-tasking, in practice this may not be the case. However, there is only a small body of research that has been conducted in this area thus far. Future research that focuses on different aspects and functions of multi-tasking may provide evidence that the strong stereotype is also evident in practice.

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Appendices

Appendix A: Ethics Approval Letter

Social Science Ethics Officer
Private Bag 01 Hobart
Tasmania 7001 Australia
Tel: (03) 6226 2763
Fax: (03) 6226 7148
Katherine.Shaw@utas.edu.au

HUMAN RESEARCH ETHICS COMMITTEE (TASMANIA) NETWORK

UTAS

14 June 2017

Dr Michael Garry
Division of Psychology
University of Tasmania

Student Researcher: Amy Cochrane

Sent via email

Dear Dr Garry

Re: MINIMAL RISK ETHICS APPLICATION APPROVAL
Ethics Ref: **H0016632 - Sex Differences in multi-tasking: Stroop Effects on Movement Symmetry**

We are pleased to advise that acting on a mandate from the Tasmania Social Sciences HREC, the Deputy Chair of the committee considered and approved the above project on 14 June 2017.

This approval constitutes ethical clearance by the Tasmania Social Sciences Human Research Ethics Committee. The decision and authority to commence the associated research may be dependent on factors beyond the remit of the ethics review process. For example, your research may need ethics clearance from other organisations or review by your research governance coordinator or Head of Department. It is your responsibility to find out if the approval of other bodies or authorities is required. It is recommended that the proposed research should not commence until you have satisfied these requirements.

Please note that this approval is for four years and is conditional upon receipt of an annual Progress Report. Ethics approval for this project will lapse if a Progress Report is not submitted.

The following conditions apply to this approval. Failure to abide by these conditions may result in suspension or discontinuation of approval.

1. It is the responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval, to ensure the project is conducted as approved by the Ethics Committee, and to notify the Committee if any investigators are added to, or cease involvement with, the project.

2. Complaints: If any complaints are received or ethical issues arise during the course of the project, investigators should advise the Executive Officer of the Ethics Committee on 03 6226 7479 or human.ethics@utas.edu.au.

3. Incidents or adverse effects: Investigators should notify the Ethics Committee immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.

4. Amendments to Project: Modifications to the project must not proceed until approval is obtained from the Ethics Committee. Please submit an Amendment Form (available on our website) to notify the Ethics Committee of the proposed modifications.

5. Annual Report: Continued approval for this project is dependent on the submission of a Progress Report by the anniversary date of your approval. You will be sent a courtesy reminder closer to this date. **Failure to submit a Progress Report will mean that ethics approval for this project will lapse.**

6. Final Report: A Final Report and a copy of any published material arising from the project, either in full or abstract, must be provided at the end of the project.

Yours sincerely

Katherine Shaw
Executive Officer
Tasmania Social Sciences HREC

Appendix B: Participant information sheet

Sex Differences in multi-tasking: Stroop Effects on Movement Symmetry

For participants

1. Invitation

You are invited to participate in a study on multi-tasking. This study is being conducted as part of a psychology honours research project undertaken by Amy Cochrane under the supervision of Dr Michael Garry from the Division of Psychology at the University of Tasmania.

2. What is the purpose of this study?

The purpose of this study is to investigate the impact of simultaneously performing two tasks. Specifically, we are investigating whether males and females differ in their ability to perform a cognitive task (Stroop task) and simple, continuous hand movement task (bimanual coordination task) simultaneously.

3. Why have I been invited to participate?

You have been invited to participate because you are a male or female between the age of 18 and 40, have normal or corrected to normal vision, are not colour blind, and don't have a reading disorder or neuromuscular or neurological disorder.
If you are female you have a regular menstrual cycle duration of 25 to 35 days, are not pregnant, and do not use the contraceptive Implanon.

4. What will I be asked to do?

The study will involve one session up to two hours duration in the Psychology Research Centre at the University of Tasmania. You will be asked to provide some initial information consisting of demographic questions like your age and sex, and will be asked to complete questionnaire assessing hand preference.
At the beginning of the study you will be shown how to perform the simple bimanual coordination task, which requires you to hold two levers and swing your wrists left to right in parallel. You will then be shown how to perform the Stroop task. To begin, there are four practice trials where you will simultaneously perform both tasks and become accustomed to what you have to do. You will then have a short break, followed by the 24 study test trials, which will take 60 seconds each. You will have breaks of one minute between trials, and can request longer breaks if you wish.
To allow us to confirm the accuracy of your responses in the Stroop task we will position a video camera behind you to record the screen and your voice responses during the study. The recordings will only be used to confirm the recording of your responses and will be erased once this is done.

5. Are there any possible benefits from participation in this study?

Your participation in this study will contribute to the scientific literature and extend our knowledge on multi-tasking and any differences between males and females. Your participation will also make a valuable contribution to the research training of Amy Cochrane for her Psychology Honours year.

If you are a first year Psychology student you will receive up to two hours course credit. If you are not a first-year psychology student, or aren't seeking course credit your name will be entered into a draw to win one of three $50 Coles-Myer vouchers.

6. Are there any possible risks from participation in this study?
There are no risks associated with participating in this study. If you become tired during the study, you can take an extended break between trials.

7. What if I change my mind during or after the study?
Participation in this study is entirely voluntary. You are welcome to withdraw from the study without consequence at any time if you wish. You are encouraged to do so if you are experiencing distress. If you withdraw after data has been collected and prior to completion of the thesis you can request that your data be removed and destroyed. However, once the data has been analysed and the thesis written your data will not be able to be removed.

8. What will happen to the information when this study is over?
All data will be replaced by an alphanumeric code, which will be recorded on your consent form. This will allow your data to be re-identified if necessary. Your identity will remain confidential for the purposes of the research and your information will not be provided to any sources without your knowledge. Any paper information will be stored of securely, in a locked cabinet at the University of Tasmania. Your electronic data will be stored securely on a password-protected computer at the University of Tasmania. Data will be kept for a minimum of 5 years after the date of publication. Once the data is no longer needed it will be securely deleted and paper copies shredded.

9. How will the results of the study be published?
The final results will be reported in an Honours thesis, which will be available to access through the UTAS Psychology Test Library. A summary of the thesis will be posted in November 2017 on the University of Tasmania's Psychology Research webpage.

10. What if I have questions about this study?
If you have any questions or concerns about the research, you are advised and encouraged to consult Amy Cochrane on amyc14@utas.edu.au (student investigator) or Mike Garry (chief investigator) on michael.garry@utas.edu.au at any time.
This study has been approved by the Tasmanian Social Sciences Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study, please contact the Executive Officer of the HREC (Tasmania) Network on +61 3 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. Please quote ethics reference number [H0016632].
Thank you for considering participating in our study.
You are welcome to keep this information sheet and refer back to it.
If you wish to participate in this study, please sign the attached consent form.

Appendix C: Participant Consent Form

Sex Differences in Multi-tasking: Stroop Effects on Movement Symmetry

<u>This form is for participants</u>

1. I agree to take part in the research study named above.
2. I have read and understood the Information Sheet for this study.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves simultaneously performing a bimanual coordination task and a Stroop task and that it will take up to two hours to complete.
5. I understand that a video camera will record my voice and the computer screen during trials to allow the researchers to confirm my responses have been accurately recorded. I also understand that these recordings will be erased once the accuracy of responses has been confirmed.
6. I understand that there are no risks associated with participating in this study
7. I understand that all research data will be securely stored on the University of Tasmania premises for a minimum of five years from the publication of the study results, and will then be destroyed.
8. Any questions that I have asked have been answered to my satisfaction.
9. I understand that the researcher(s) will maintain confidentiality and that any information I supply to the researcher(s) will be used only for the purposes of the research.
10. I understand that the results of the study will be published so that I cannot be identified as a participant.
11. I understand that my participation is voluntary and that I may withdraw at any time without any effect.

    If I so wish, I may request that any data I have supplied be withdrawn from the research.

Participant's name:

____

Participant's signature:

____

Date: ________________________

Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

Investigator's name:

____

Investigator's signature:

____

Date: ________________________