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Garden Path Sentence Processing as a Measure of Belief Updating

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Abstract

Handedness is a marker for individual differences in brain organization. Garden path sentences (GPS), those that require a mid-sentence change in understanding to capture sentence meaning require the updating of beliefs via the right hemisphere. Inconsistent-handers (ICH) have increased access to right hemisphere processes, which has previously been shown to result in increased belief updating. It was hypothesized that ICH would be more accurate and more rapid in their processing of GPS relative to consistent right handers (CRH) due to increased access to the neural structures involved. Additionally, men and women differ in their brain organization, and in their cortical representation of language. It was therefore hypothesized that differences in GPS processing may occur as a function of gender. Results revealed decreased speed of processing of GPS in ICH versus CRH, and processing of typical and non-sentences faster in ICH relative to CRH, with the effect holding especially true for men. Results tentatively support individual differences in sentence processing as a function of handedness, which may be mediated by gender. Increased, rather than decreased, reaction time in ICH for GPS may reflect increased atypical representation of language functions in ICH. Future work should replicate this study with a larger sample of men.

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Garden Path Sentence Processing as a Measure of Belief Updating

By

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Individual differences in handedness have been shown to be associated with individual differences in cognition (Christman, Propper, Phaneuf, 2005; Christman, et al., 2008; Christman, et al., 2006a; Khedr, et al., 2002; Knecht, et al., 2000a). Particularly, individuals who are inconsistently-handed (ICH) differ from consistently-right-handed individuals (CRH) in a number of cognitive domains including memory and emotion (see Prichard, Propper, & Christman, 2013 for a review). Support for better cognitive processing of memory in inconsistent-handers exists across multiple measures of memory, including age of earliest childhood memory (Christman, Propper, & Brown, 2006), memory for faces (Lyle & Osborn, 2011), personal autobiographical memory (Propper, Christman, & Phaneuf, 2005), cued recall (Lyle, 2018), associative word lists (Lyle, Hanaver-Torrez, Hacklander, & Edin, 2012), and incidental learning (Christman & Butler, 2011). For example, Propper & Christman (2004) investigated handedness strength and "remember vs. know" judgements, presumed to indicate selective reliance on episodic vs. semantic memory systems. Tests of recognition memory, designed to distinguish whether a stimulus was explicitly *remembered* or if it was implicitly *known*, were administered to a group of consistent- and inconsistent-handed participants (Propper & Christman, 2004). Mixed handers were significantly more likely than consistent-handers to endorse "remembering" versus "knowing" judgements. In other words, handedness significantly impacted the process by which inconsistent-handers processed the stimuli relative to consistent-handers.

Individual differences in handedness are associated with individual differences in cortical organization, such that inconsistent-handers have been shown to have increased access to right hemisphere processing. Individual differences in cortical organization as a function of handedness have been supported by neuroimaging studies (Trehout, et al., 2017; Lane, et al., 2017; Khedr, et al., 2002; Lei, et al., 2018). For example, Khedr, Hamed, Said & Basahi (2002) used repetitive transcranial magnetic stimulation (rTMS) to assess the lateralization of language in a sample of 50 medical students (24 CRH, 5 ICH, and 19 consistent-left-handers (CLH)). Left-side language dominance was observed in 87.5% of consistent-right-handers and 73.7% of consistent-left-handers. Meanwhile, only 43% of inconsistent-handers had left-side cerebral dominance of language. Importantly, bilateral representation of language was observed in 57% of inconsistent-handers, but only in 8.2% of consistent-right-handers and 15.8% of consistent-left-handers, indicating a significantly greater number of inconsistent-handers with anomalous language lateralization (Khedr, Hamed, Said, & Basahi, 2002). Lateralization of language is a cortical organization trait that varies with individual differences in handedness. Individual differences in cortical morphology have also been associated with individual differences in handedness (Luders, et al., 2010). Inconsistent-handers, on average, have significantly thicker corpus callosum relative to consistent-right-handers (Luders, et al, 2010). Luders, et al. (2010) used the surface-based mesh modeling technique on 3-D structural magnetic resonance imaging (MRI) images to compare the thickness of the corpus callosum between right- and left-handers at 100 equidistant points along the midsagittal surface in a sample of 361 adults. The Edinburgh Handedness Inventory (EHI) was used to assess handedness direction and degree. A negative association between absolute handedness scores (representing degree of handedness) and callosal size was observed, indicating that individuals with more consistent-handedness (either strong right- or left-handers) had smaller corpus callosum than inconsistently-handed individuals (Luders, et al., 2010). Researchers have also demonstrated a correlation among inconsistent-handedness and increased right hemisphere activity (Propper, et al., 2012). Propper, et al. (2012) examined the resting alpha activity via EEG in 22 inconsistent- and consistent-right-handers. When participants kept their eyes open during the EEG measurement, Propper, et al., (2012) observed that inconsistent-right-handers demonstrated decreased left hemisphere activation and increased right hemisphere activation as measured by a lateralization index (left hemisphere-right hemisphere)/(left hemisphere + right hemisphere) relative to consistent-right-handers. Taken together, the increased anomalous lateralization of language observed in inconsistent-handers, their larger corpus callosum size, and the observation of increased right hemisphere activity at rest in inconsistent-handers, supports the claim that inconsistent handers have increased access to the right hemisphere.

In summary, inconsistent handedness associates with increased right hemisphere access and individual differences in cognition. Inconsistent-handers have been shown to possess increased right hemisphere access based on a number of neuroimaging studies as well as findings demonstrating that, on average, inconsistent-handers have a larger corpus callosum, which would provide the greater volume of neuronal connection that would underlie such increased access (Christman, et al., 2008; Luders, 2010).

Inconsistent-handers' increased right hemisphere access may underlie observations of inconsistent-handedness advantages in a number of cognitive tasks involving the right hemisphere, including free recall of words, source memory, face memory, false memory, placebos, magical ideation, sensation seeking, sleep architecture, baseline emotional state, openness to persuasion, and belief-updating (Propper, et al., 2005; Christman, et al., 2006; Lyle, et al., 2008; Lyle & Osborn, 2011; Christman, et al., 2008).

Defined by Ambeuhl & Li (2018) as “the ability and tendency to change one’s beliefs due to new information”, belief updating is a cognitive construct that is associated with the right frontal parietal areas of the brain (Ambeuhl & Li, 2018). Ramachandran, (1995) posited the theory that the left hemisphere is involved with maintaining beliefs about the world, while the right hemisphere detects information that is inconsistent with currently held beliefs, like an incongruity detector. This theory suggests one possible role for right hemisphere access in belief updating. Belief updating ability has been shown to vary significantly between individuals (Christman, Henning, Geers, Propper, & Neibauer, 2008; Ambeuhl & Li, 2018). Evidence has linked propensity for belief updating to lateralized activation, such that increased right hemispheric access is associated with greater belief updating (Drake, 1993; Drake, 1991; Christman, et al., 2006; Christman, et al., 2008). In contrast, greater resistance to persuasion and higher belief maintenance is associated with left hemisphere activation (Drake, 1993). Taking the preferential involvement of the right hemisphere in belief-updating in context with studies supporting increased access to right hemisphere processes in inconsistent-handers, the current study aimed to determine if inconsistent-handers demonstrate a superior ability for belief updating relative to consistent-right-handers as measured by ambiguous sentence processing using the garden path sentences. In addition to the findings of increased right hemisphere access in inconsistent-handers relative to consistent-right-handers and findings of increased right hemisphere access during belief updating, the additional rationales for the experiment are laid out in two parts: 1. Previous findings of superior believe updating in inconsistent-handers relative to consistent-right-handers and 2. That ambiguous sentence processing with garden path sentences is a measure of believe updating. Each of these links in the chain of logic will be discussed in turn.

First, a number of studies have demonstrated inconsistent-handers advantages in a number of dependent variables assessing belief updating ability. Christman, et al. (2008) demonstrated that inconsistent-handers are significantly more open to persuasion, as well as more susceptible to gullibility measures, than consistent handers, indicating an increased willingness to update their beliefs. In the first experiment in this study, undergraduates (n=144; ICH=57; CRH=82) were asked to give their opinion on a personally applicable argument (the introduction of comprehensive senior exams) before and after being exposed to a strong and weak argument in favor of the exams. Christman, et al. (2008) observed a significant interaction between handedness and pre-post opinion, such that inconsistent-handers showed a bigger change in opinion relative to consistent-right-handers. While both handedness groups exhibited a change in pre- and post-argument ratings, the effect size was twice as large for inconsistent-handers (d=2.0) relative to consistently-right-handed (d=0.98). Christman, et al. (2008) also observed gender-mediated differences in degree of agreement with the strong versus weak argument such that consistently-right-handed females and inconsistent-handers males agreed more strongly with the strong argument than inconsistently-handed females and consistently-right-handed males, indicating potential complex effects of gender and handedness on belief-updating.

Christman, Henning, Geers, Propper, & Neibauer (2008) also investigated susceptibility to the Barnum Effect as an assessment of belief-updating propensities in consistent right- relative to inconsistent-handers. The Barnum Effect is the tendency of individuals to accept specific types of self-referent information, like horoscopes or suggested personality traits, as true and uniquely applicable to them, even when the information is vague and could apply to anyone (Dickson & Kelly, 1985). Christman, et al. (2008) tested 184 undergraduates on this paradigm by administering a personality inventory, then providing a bogus list of 18 traits that were supposedly generated by the personality assessment, and then tasking participants with rating the degree to which the traits represented their true personality. Half of the participants were told the personality assessment was experimental and that their ratings of the traits would be used to assess the accuracy of the personality assessment while the other half believed they were taking an established assessment. Christman, et al. (2008) observed a significant effect of handedness (d=0.44) reflecting a tendency of inconsistent-handers to agree more strongly with the bogus traits than consistent-right-handers, indicating higher susceptibility to the Barnum Effect in inconsistent-handers relative to consistent-right-handers. The higher levels of suggestibility observed in this study suggests inconsistent-handers more readily update current beliefs (Christman, et al., 2008).

Neibauer, et al. (2004) suggested that inconsistent-handers may exhibit a “lower threshold for updating beliefs,” supported by their findings that inconsistent-handers were more likely than consistent-right-handers to hold evolutionary, versus creationist, beliefs about the origins of the Earth. Holding creationist beliefs in adulthood is considered a marker for a lack of belief updating, as it is presumed that an adult will have encountered significant evidence contradictory to creationist beliefs. In the first of two related experiments, Niebauer, Christman, Reid, & Garvey (2004) administered the EHI and a creationism/evolution (C/E) scale to a sample of 143 undergraduates at a midwestern University, and found that among participants with no familial handedness, absolute EHI score negatively correlated with C/E belief score, indicating that consistently-handed individuals were more likely to hold creationist beliefs relative to inconsistent-handers ($r=-.29$; $p<.003$). The same procedure was later replicated in a sample from a different midwestern university ($n=123$), where a negative correlation was observed between absolute EHI score and C/E beliefs ($r=-.28$). Both studies observed an association between inconsistent-handedness, lower levels of creationist beliefs, and higher levels of belief in evolution. This finding provides further support to the claim that inconsistent-handers exhibit superior belief updating relative to consistent-right-handers.

Neibauer, Aselage, & Schutte (2002) presented a model for increased belief updating in inconsistent-handers, based on findings that consistent-handers have reduced ability to update their beliefs in response to a sensory illusion relative to inconsistent-handers. Neibauer, Aselage, & Schutte (2002) conducted two experiments using a “false hand illusion” adopted from Botvinick & Cohen (1998), which involved presenting simultaneous stimulation to a participants’ real hand, which was hidden out of sight, as well as a fake hand, which was held plainly in view. Niebauer, Aselage, & Schutte (2002) predicted that propensity to experience this illusion, and the speed with which one perceived the illusion, related to individual differences in belief updating and handedness. They predicted that inconsistent-handers, who are presumed to have greater degrees access to right hemisphere processes, would exhibit more efficient belief-updating. In their first experiment, Niebauer, Aselage, & Schutte (2002) ran 48 students (39 female) through the “false hand” sensory illusion, after which they were asked to report the degree to which they experienced the illusion and respond to the EHI. Handedness scores were significantly negatively associated with illusion scores ($r=-.295$; $p<0.042$), supporting Niebauer, Aselage, & Schutte’s (2002) main hypothesis that consistent handedness (as indicated by EHI scores relatively further from zero) would associate with lesser experience of the illusion, suggesting a higher degree of belief-updating in inconsistent-handers. In a follow-up experiment, Niebauer, Aselage, & Schutte (2002) conducted a similar experiment on a different group of 48 undergraduates (33 females) who underwent the same “false hand” illusion, but this time were asked to report as quickly as possible when they felt the illusion during the protocol. Again, results indicated that more consistently-handed individuals felt the illusion less strongly (between absolute EHI and degree of illusion perception, $r=-.429$; $p<.037$). Additionally, inconsistent-handed participants felt the illusion more quickly relative to consistently-handed individuals. These results indicate a belief-updating advantage in inconsistent-handers, based on replicated evidence that inconsistent-handers were more both likely to experience the false hand illusion in two studies, and that they are likely to experience it far more quickly relative to consistently-handed individuals (Niebauer, Aselage, & Schutte, 2002). In summary, individual differences in handedness correlate with individual differences in cognition. Likewise, individual differences in cognition also correlate with individual differences in cortical organization. Inconsistent handers have been shown to have increased access to the right hemisphere, where the structures presumed to be preferentially involved in belief-updating are located. In accordance with these findings, prior research has found that inconsistent-handers demonstrate increased belief updating in response to various paradigms used to measure the construct, including the Barnum effect and the maintenance of young Earth beliefs (Christman, et al., 2008; Neibauer, et al., 2004) . The current study aimed to extend these findings to ambiguous sentence processing, another measure of belief-updating, using garden path sentences (GPS).

Garden path sentences are a measure of belief updating (Feeney, Coley, & Crisp, 2010). Garden path sentences may provide a tool for understanding how individuals "integrate incoming new information into a previously computed analysis and how apparent conflicts are resolved" (Jacob & Fesler, 2015). The garden path sentence paradigm uses syntactic ambiguities in run-on sentences to necessitate belief updating (Christianson, et al., 2007). The disambiguation process required in the parsing of garden path sentences is analogous to the process of belief updating, which is described in the literature as the process of "changing one's beliefs in response to new information" (Ambeuhl & Li, 2018).

Garden path sentences are temporarily ambiguous sentences that are structured such that the reader's initial understanding is untenable and requires reanalysis. An example of a garden path sentence is *When Fred eats food gets thrown,* where the noun *food* is likely to be first interpreted as the direct object of *eats* in the subordinate clause, where in fact it is the subject of the main clause (*food gets thrown*) and *When Fred eats* is a precipitating clause (Christman & Campbell, 2013). This paradigm allows researchers to investigate the syntactic processing of the reader, and the response time needed to resolve temporary ambiguity and build a mental representation of the sentence's meaning (Malyutina & den Ouden, 2016).

Different event-related-potentials (ERPs) have been observed during the parsing of ambiguous relative to unambiguous sentences (van Herten, Chwilla, & Kolk, 2006). van Herten, Chwilla, & Kolk, (2006) used EEG to observe the ERPs of participants during the parsing of straightforward sentences and ambiguous sentences that required disambiguation for appropriate parsing. An effect of ambiguous sentences was observed such that the P600 effect, an ERP distinctly observed during the parsing of syntactic ambiguity, was observed during disambiguation of ambiguous sentences but not during the parsing of normal sentences (van Herten, Chwilla, & Kolk, 2006). The P600 effect has been shown to be distinct from another ERP, the N400, that is consistently observed while perceiving words that do not fit the context of a sentence (Osterhout & Holcomb, 1992). The observation of unique ERPs during the processing of syntactically ambiguous sentences, along with the long history of garden path sentence use in the study of belief-change suggest that syntactically ambiguous sentences are an acceptable measure of belief-updating.

Based on findings of superior belief-updating in inconsistent-handers relative to consistent-right-handers, it was hypothesized that inconsistent-handers may have an advantage in the processing of garden path sentences, which require effortful disambiguation on the part of the reader (Malyutina & den Ouden, 2016). It was hypothesized that the inconsistent-handed advantage would manifest as faster and more correct categorization of garden path sentences into semantic categories.

Given that inconsistent-handers have greater access to right hemisphere processes, belief updating may preferentially involve the right hemisphere, inconsistent-handers have been shown have increased belief updating relative to consistent-right handers in other belief-updating paradigms, and garden path sentences are thought to utilize belief-updating, it was hypothesized that inconsistent handers may demonstrate an advantage over consistent-right-handers in a proposed measure of belief updating, ambiguous sentence processing using garden path sentences. This study is the first to assess the cognitive construct of belief updating using the linguistic paradigm of garden path sentences.

Methods

Participants

This protocol was approved by the Montclair State University Institutional Review Board (IRB#001511), and all ethical requirements as determined by the Declaration of Helsinki and all applicable alterations and addendums were followed. Undergraduate college students (n=114, 90 female, 21 male; M_{age}=19.6 years old; age range: 18-25) were recruited from the SONA research participant pool of Psychology 101 and Psychology 203 students at Montclair State University.

Participants were compensated with one SONA credit out of the six required for their courses. Participants were screened for English as their native language as well as normal or corrected-to-normal hearing and vision.

Materials

Edinburgh Handedness Inventory. Inconsistent-handedness was determined using the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). The EHI is an inventory of ten everyday actions that are traditionally performed with one dominant hand, including writing, drawing, throwing, using scissors, brushing teeth, using a knife and spoon, using a broom, striking a match, and opening a jar. Participants report with which hand they perform the action on a five-item scale (-10: always left; -5: mostly left; 0: either hand; +5: mostly right; +10: always right). A handedness coefficient is calculated for each participant by summing their scores on the ten items. The resulting handedness coefficients ranged from -100 to +100 and comprised both the participant's direction and degree of handedness. Negative values indicated left-handedness and positive values indicated right handedness, while values farther from 0 indicated stronger lateralization.

Garden Path Sentence Paradigm. Garden path, normal, and nonsense sentences used in this study originated from a set used in a previous study (Christman & Campbell, 2013). 18 garden path sentences, 18 normal sentences (simple and compound sentences), and 18 nonsense sentences (sentences lacking either a subject or a verb with no meaning) were used in this study, representing the full set of sentences from Christman and Campbell (2013). Participants were randomly presented 18 GPS sentences, 18 normal sentences, and 18 nonsense sentences via Superlab 5.0.5. (see Figure 5 in Appendix for complete list of sentences). Sentences were presented on a 21.5" Macintosh computer screen (iMac desktop model), and sentences were presented in black non-serif 30 pt. font on a white background.

Procedure

Participants were tested individually in the Lateralization Lab at Montclair State University. Before signing up, participants were excluded for non-normal vision and for not claiming English as their native language. Participants were led to a private room with a desk, computer, and filing cabinet. They were asked to sit at the computer and fill out an informed consent form. The directions were then presented on the computer and simultaneously read aloud to them by a research assistant. Instructions were as follows, "*In this study you will be presented with sentences. Your task is to determine whether or not the sentences are meaningful in the English language. Press the "yes" key on the keyboard if the sentence makes sense. Press the "no" key if the sentence does NOT make sense. Please respond as quickly and accurately as possible. Keep your fingers resting on the "yes" and "no" keys throughout the duration of the experiment. The first two sentences are practice sentences. Do you have any questions? Please let the experimenter know when you are ready to begin the two practice sentences.* After the instructions were read, participants completed two practice trials that included a nonsense sentence and a normal sentence. Response time and accuracy were tracked by Superlab. Participants responded to each sentence by pressing one of two buttons reading "yes" or "no". Stickers reading "yes" and "no" were adhered to the 'X' and 'M' keys on a standard QWERTY keyboard (Apple Magic Keyboard-US English version), representing the two possible responses: either "yes, the sentence is meaningful" or "no, the sentence is not meaningful" (response keys were counterbalanced between participants). No feedback was given after responses, and the sentences remained on the screen until a response was given. After the two practice sentences, the instructions were presented and read a second time. This time, the last sentence read, "*Please press the spacebar to begin*." Next, the participant was instructed to press the space bar to start the presentation of sentences, and the research assistant stood outside the door while the participant completed the task.

When the Superlab task was completed, the research assistant returned to the room, saved the data, and opened the online survey which was presented on Qualtrics. Participants were instructed to read the directions for the survey carefully and to get the research assistant when they were finished. At this point, the research assistant again left the room and participants completed the EHI (Oldfield, 1970), as well as the Behavioral Inhibition/Behavioral Approach Survey (BIS/BAS) and the Cognitive Failures Questionnaire (CFQ) as distractor tasks (to be reported elsewhere). Upon completion of the questionnaires, they were debriefed, given a signed copy of their consent form, and dismissed. Appointments lasted on average 15 minutes from participant arrival to dismissal.

Planned Analyses

Two mixed-ANOVAs, 2 (Handedness: ICH, CRH) x 3 (Sentence Type: GPS, normal, nonsense) were cnducted on reaction time and accuracy. Two additional identical ANOVAs of 2 (handedness group) x 3 (sentence type) were conducted for response time and accuracy in men and women separately.

Results

Three individuals who scored ‘0’ correct for GPS were excluded from analyses, bringing total sample size for the following calculations to 111 participants. A handedness coefficient was determined for each participant using the EHI (Oldfield, 1971). Participants that scored above the median (median: +80) were considered consistently-right-handed (n = 57) and participants scoring between -70 and +85 were classified as inconsistent-handed (n = 54; EHI ranged from -100 to +100; see Prichard, Propper, and Christman, 2013). Participants who scored less than -70 on the EHI were excluded from this study due to population constraints on consistent left handers (n=6; there are simply too few consistent left handers to recruit a powerful sample of them from the general population without targeted recruitment). Correctly answered items were summed by sentence type. Response time for each sentence correctly categorized was averaged to obtain the mean response time for each of the different sentence types.

The 2 (handedness: CRH, ICH) x 3 (sentence type: GPS, normal, nonsense) mixed ANOVA for response time returned a significant main effect of Sentence Type ($F(2, 226)=117.025$), $p<0.001$) (see Table 1 for descriptive statistics). This effect signifies that the different sentence types elicited significantly different response times, with garden path sentences eliciting the slowest response times (see Figure 1). There was also a significant interaction between Sentence Type and Handedness Group, such that inconsistent-handers responded more slowly than consistent-right-handers to GPS ($F(2, 232)=3.071$, $p<0.048$) (see Table 1 for descriptive statistics). The 2 (handedness: CRH, ICH) x 3 (sentence type: GPS, normal, nonsense) mixed ANOVA for accuracy returned a significant main effect for Sentence Type ($F(2, 232)=729.89$; $p<0.001$; see Figure 2), with the garden path sentences eliciting the lowest accuracy relative to normal and nonsense sentence types. The interaction between Sentence Type and Handedness was not significant ($F(2, 232)=0.087$, n.s.).

Given the imbalance of the Gender x Handedness cells (ICH men = 9, ICH women=44, CRH men=12, CRH women=43), ANOVAs for Accuracy and Response Time were conducted for males and females separately (2 (Handedness) x 3 (Sentence Type) (see Tables 3 and 4 for descriptive statistics).

In women, two 2 (Handedness) x 3 (Sentence Type) ANOVAs were run for the dependent measures of Accuracy and Response Time (see Figures 3 and 4). The interaction between Sentence Type and Handedness for response time and accuracy was nonsignificant ($F(2,38)=0.289$, n.s.; $F(2, 170)=0.020$, n.s., respectively). The main effects and interactions of handedness for Response Time and Accuracy were not significant for women ($F(1,85)=0.033$, n.s.; $F(1,85)=0.021$, n.s., respectively), but there was a significant main effect of Sentence Type for both Response Time and for Accuracy that was identical to that of the overall ANOVA ($F(2,38)=138.441$, $p<0.001$; $F(2, 170)=654.15$, $p<0.001$, respectively; see Tables 5 and 6). These data indicate that, in women, there was decreased accuracy and increased response time in response to garden path sentences, relative to the other two sentence types, the same as in the overall sample.

The same analyses were run for men for both the response time and accuracy dependent measures (2 (Handedness) x 3 (Sentence Type)). The main effect of handedness for response time and accuracy was not significant for men ($F(1,19)=0.017$, n.s.; $F(1,19)=0.067$, n.s., respectively), but there was an unsurprising significant main effect of sentence type for response time and accuracy ($F(2,38)=21.184$, $p<0.001$; $F(2, 38)=138.44$, $p<0.001$, respectively; see Table 7 and 8). The interaction between sentence type and handedness for response time was significant ($F(2,38)=3.27$; $p<.05$), indicating that handedness group and sentence type influenced response time such that inconsistent-handers responded significantly more slowly than consistent-right-handers to garden path sentences, but responded at relatively the same speed as consistent-right-handers to normal and nonsense sentences. The interaction between sentence type and handedness for accuracy was nonsignificant ($F(2,38)=0.123$, n.s.). The same interaction wsa found in men as in the overall sample (see Figures 3 and 4).

Discussion

The goal of the current study was to examine the effect of individual differences in handedness on belief-updating using a garden path sentence paradigm to target belief updating. Results indicate that belief updating, as measured by accuracy using the garden path sentence paradigm, is not significantly associated with strength of handedness. It's unclear why significant results were not found with accuracy; it is possible that the task was too difficult, resulting in highly variable accuracy scores more influenced by understanding of the directions than any other variable. Response time in the categorization of garden path sentences, on the other hand, was significantly associated with handedness. Results revealed decreased speed of processing of garden path sentences in inconsistent-handers versus consistent-right-handers. The effect was more pronounced in males and failed to reach significance in females. The results of the current study reflect a modest effect of gender, and a primary effect of handedness on belief updating as assessed by response time in the garden path sentence task.

The results of the current study trended such that inconsistent-handers took longer to process garden path sentences, and shorter time to process normal and nonsense sentences than consistent-right-handers. This pattern of results conflicts with prior observations of the inconsistent-handed advantage in belief updating. The observed results were inconsistent with the current study's hypothesis, which predicted that inconsistent-handers would perform better than consistent-right-handers in accuracy and have a faster response time in the belief-updating task (Prichard, et al., 2013).

There are a number of possible explanations for these findings. It is possible that the belief updating necessitated by the garden path sentence disambiguation may have required greater cognitive effort in inconsistent-handers and thereby increased response time. Perhaps the bilateral language representation that is observed significantly more often in inconsistent-handers resulted in interference between the two hemispheres resulting in slower response times. Observations of increased processing time, but not decreased accuracy, in inconsistent-handers relative to consistent-right-handers in response to garden path sentences may support this hypothesis. If this is the case, and inconsistent-handers with bilateral language representation take longer to process information, longer response times might be expected in inconsistent-handers. It is possible that the assumption that inconsistent-handers predictably demonstrate increased right hemisphere access is incorrect. While there is evidence demonstrating that this is not the case, it is foreseeable that the association is not as straightforward as originally proposed, and that there are additional factors affecting right hemisphere access and belief-updating in inconsistent-handers relative to consistent-right-handers. For example, perhaps right hemisphere access is not stronger in inconsistent-handers, but simply more variable, in a pattern similar to the lateralization of language in inconsistent handers. Knecht, Dräger, & Deppe et al., (2000b) observed increased incidence of atypical right-hemispheric language in left-handed individuals and that the incidence increased linearly with the strength of an individual's left handedness, from 4% in consistent right handers to 15% in mixed handers, and then to 27% in consistently left-handed individuals. It is conceivable that the current findings may have been affected by the higher incidence of atypical language lateralization in inconsistently handed individuals. Further research is necessary to understand the neural structures and systems underlying belief-updating and the effect that individual differences in cortical organization make on the successful processing by such structures and systems.

It is not clear why men, relative to women, are more likely to demonstrate the observed effects of handedness on reaction time. Evidence indicates men are ore lateralized for language, which may underlie some of the observable differences between males and females as well as the significant result in men that was not observed in women (e.g. Cahill, 2006). Unfortunately, only a small sample of men could be recruited for the present study, introducing a number of limitations to the findings on the interaction of gender and individual differences associated with handedness. Future studies should certainly be conducted with a larger sample of men.

One significant interaction was observed in response timing by sentence type, such that both men and women responded to garden path sentences more slowly than they responded to normal and nonsense sentences ($p<0.05$ for both men and women; see Figures 1, 7 and 8). This finding supports the garden path sentences as being different from the other two types of sentences, and therefore requiring different types (perhaps) of processing. The significant effect of sentence type on response time and accuracy mirrors similar findings that garden path sentences are more difficult and require more complex processing than normal and nonsense sentences (Novick, Hussey, Teubner-Rhodes, Harbison, & Bunting, 2013; Christianson, Luke, & Hussey, et al., 2017). The garden path sentence paradigm was chosen as a measure of belief-updating to require additional processing via disambiguation and the slower reaction times and reduced accuracy relative to the syntactically simpler normal and nonsense sentences support the function of this paradigm in the present study. Additionally, the longer reaction times necessary to respond to the syntactically trickier garden path sentences suggests that participants were earnestly reacting to each sentence and committing observable, motivated effort into the processing of each sentence.

There were several limitations to the current study. First, the sample size, which was limited by the availability of research participants seeking credit in the SONA system, fell short of supplying sufficient power to detect the hypothesized relationships confidently. It is possible that, for the expected effect size of the association of handedness and the outcome measures, more significant effects might have been found in a larger sample. Due to limited sample size, the number of participants in each cell of the 2x2 ANOVAs separated by gender was low in the case of male participants. While the proportion of men to women in the SONA participant pool is notoriously low, gender unbalance should be rectified in future experiments.

Another limitation lies in the lack of a consistently-left-handed group. Consistently left-handers are present in the population at a far lower rate compared to consistent-right-handers and inconsistent-handers, and while we tested seven consistent-left-handers in the initial sample, they were excluded because there were only three or four participants per cell for consistent-left-handers in the ANOVAs. Therefore, the results reported in this study are generalizable only to consistent-right- and inconsistent-handers. Future studies should focus on the targeted recruitment of a group of consistent-left-handers.

Studies of handedness across child development should aim to observe whether differences in language development are present in consistent-left-handers with atypical right hemisphere language processing. Additionally, the theory that inconsistent-handers have greater right hemisphere access due to the observation of a larger corpus callosum and differences in cognitive ability should be confirmed using functional neuroimaging methods.

Handedness research may someday help explain some of the innate individual differences observed among humans. In the immediate future, the field should focus on 1) confirming the basic assumptions of the field through well-powered neuroimaging studies, 2) undertaking meta-analyses to better understand the wider findings and effect sizes present in the field, and 3) distinguishing the basic cognitive correlates of individual differences in handedness with well powered studies that include large samples of men and consistent-left-handers.

Tables

Table 1

Means and Standard Deviations for Response Time as a function of Handedness and Sentence Type

Handedness Group	Sentence Type	Mean	Standard Deviation
CRH	GPS	5132.18	1626.89
(N=55)	Normal	3453.67	987.31
	Nonsense	3875.13	1371.95
ICH	GPS	5751.15	2872.75
(N=56)	Normal	3487.20	1065.22
	Nonsense	3915.27	1437.29

Note: Response time measured in milliseconds.

Table 2

Means and Standard Deviations for Accuracy as a function of Handedness and Sentence Type

Handedness Group	Sentence Type	Mean	Standard Deviation
CRH	GPS	5.79	2.51
(N=55)	Normal	16.83	2.02
	Nonsense	16.49	1.74
ICH	GPS	5.95	2.60
(N=56)	Normal	17.16	2.08
	Nonsense	16.56	1.49

Table 3.

Means and Standard Deviations for Accuracy as a function of Handedness, Gender, and Sentence Type

Handedness Group	Gender	Sentence Type	Mean	Standard Deviation
ICH	Female	GPS	5.81	2.71
(N=46)		Normal	16.56	2.06
		Nonsense	17.09	1.81
ICH	Male	GPS	6.44	2.24
(N=9)		Normal	16.22	1.86
		Nonsense	16.78	1.92
CRH	Female	GPS	5.95	2.61
(N=43)		Normal	16.58	2.08
		Nonsense	17.07	1.62
CRH	Male	GPS	6.58	2.35
(N=12)		Normal	16.01	2.73
		Nonsense	17.25	1.48

Table 4

Means and Standard Deviations for Response Time as a function of Handedness, Gender, and Sentence Type

Handedness Group	Gender	Sentence Type	Mean	Standard Deviation
ICH	Female	GPS	5259.78	2353.54
(N=46)		Normal	3743.87	1132.45
		Nonsense	3417.98	913.67
ICH	Male	GPS	5952.95	3654.56
(N=9)		Normal	3821.05	2146.45
		Nonsense	3456.33	1514.82
CRH	Female	GPS	5225.51	1529.95
(N=43)		Normal	3921.04	1384.86
		Nonsense	3416.48	906.11
CRH	Male	GPS	4956.43	2035.12
(N=12)		Normal	4194.28	1704.07
		Nonsense	3740.66	1392.21

Note: Response time measured in milliseconds.

Figures

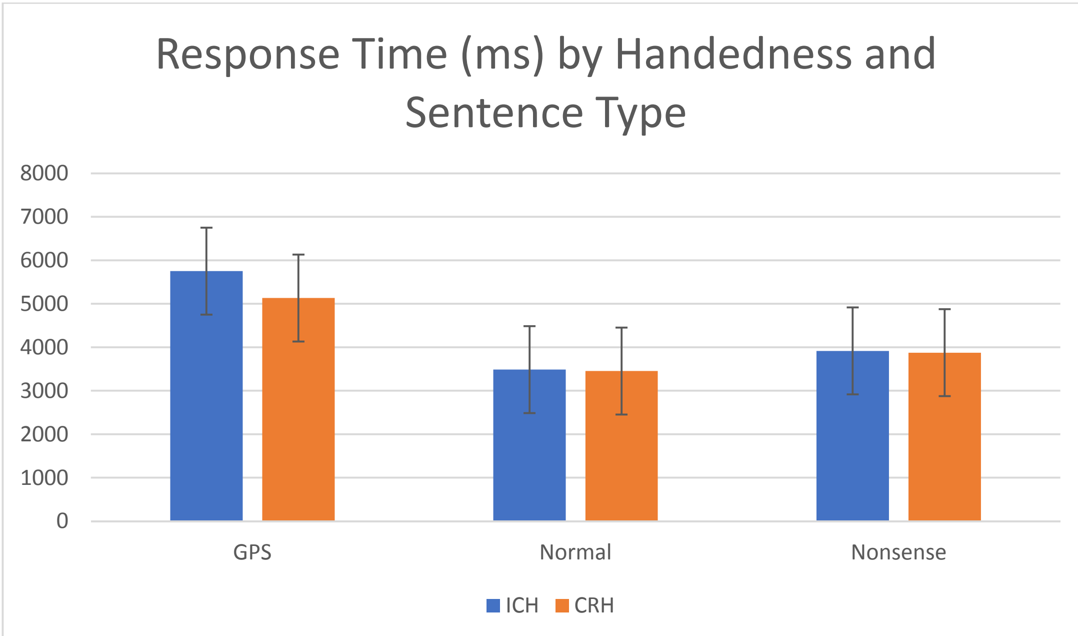

Figure 1. Response time (in milliseconds) by Handedness and Sentence Type. Garden path sentence response times were significantly longer than normal and nonsense response times. Normal and nonsense sentences also elicited significantly different response times. Error bars indicate standard deviation.

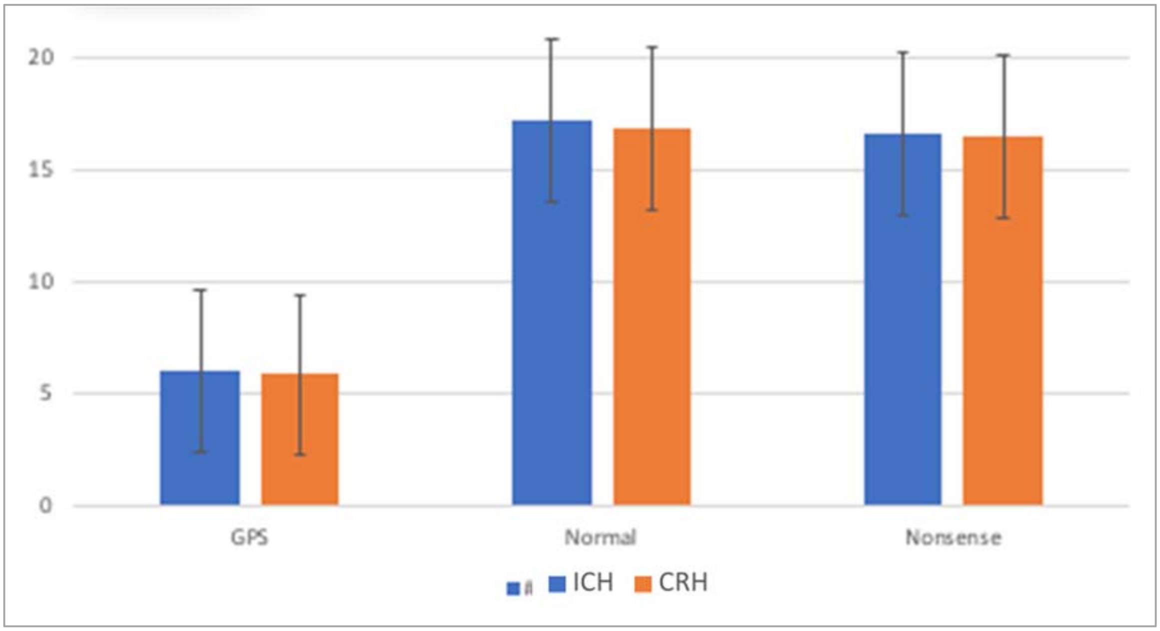

Figure 2. Accuracy by handedness group (inconsistent-handed (ICH) and consistent-right-handed (CRH)) and sentence type (garden path sentence (GPS), normal, and nonsense sentences) (n=111). Garden path sentence accuracy was significantly lower than normal and nonsense accuracy. Error bars indicate standard deviation.

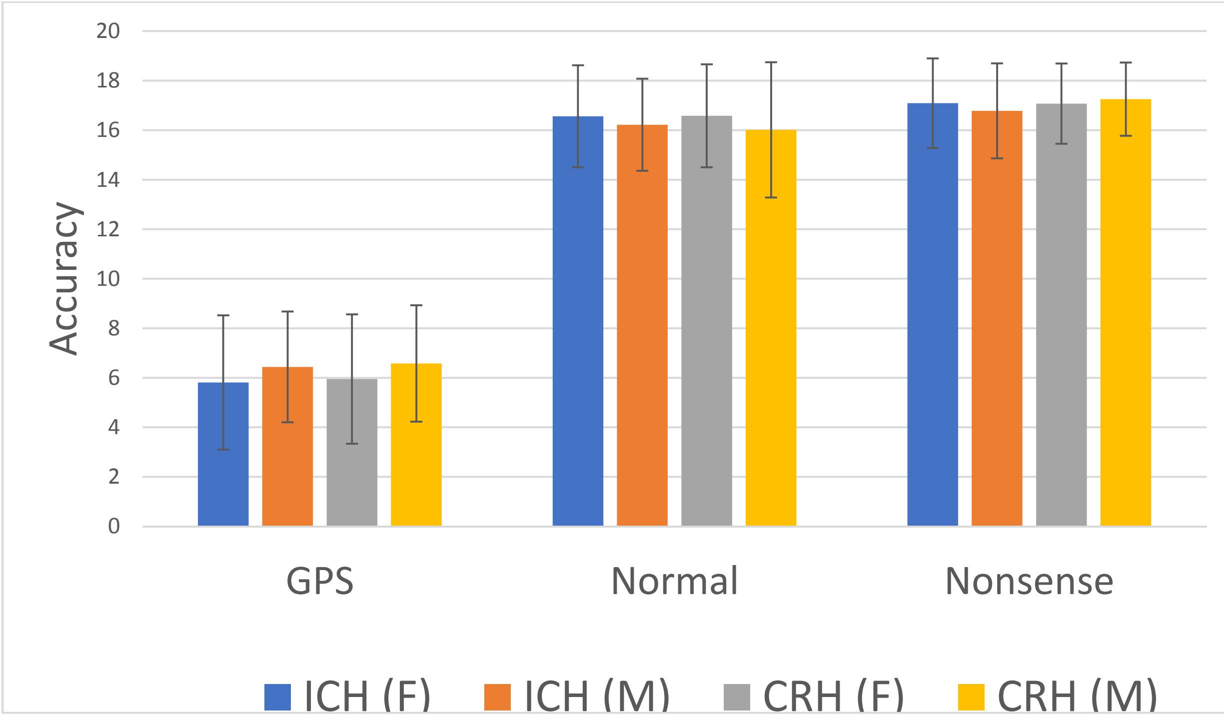

Figure 3. Accuracy by handedness (inconsistent-handers (ICH) and consistent right-handers (CRH)) and sentence type (garden path sentences (GPS), normal sentences (Normal), and nonsense sentences (Nonsense)) separated by gender. Error bars represent standard deviation. Error bars indicate standard deviation.

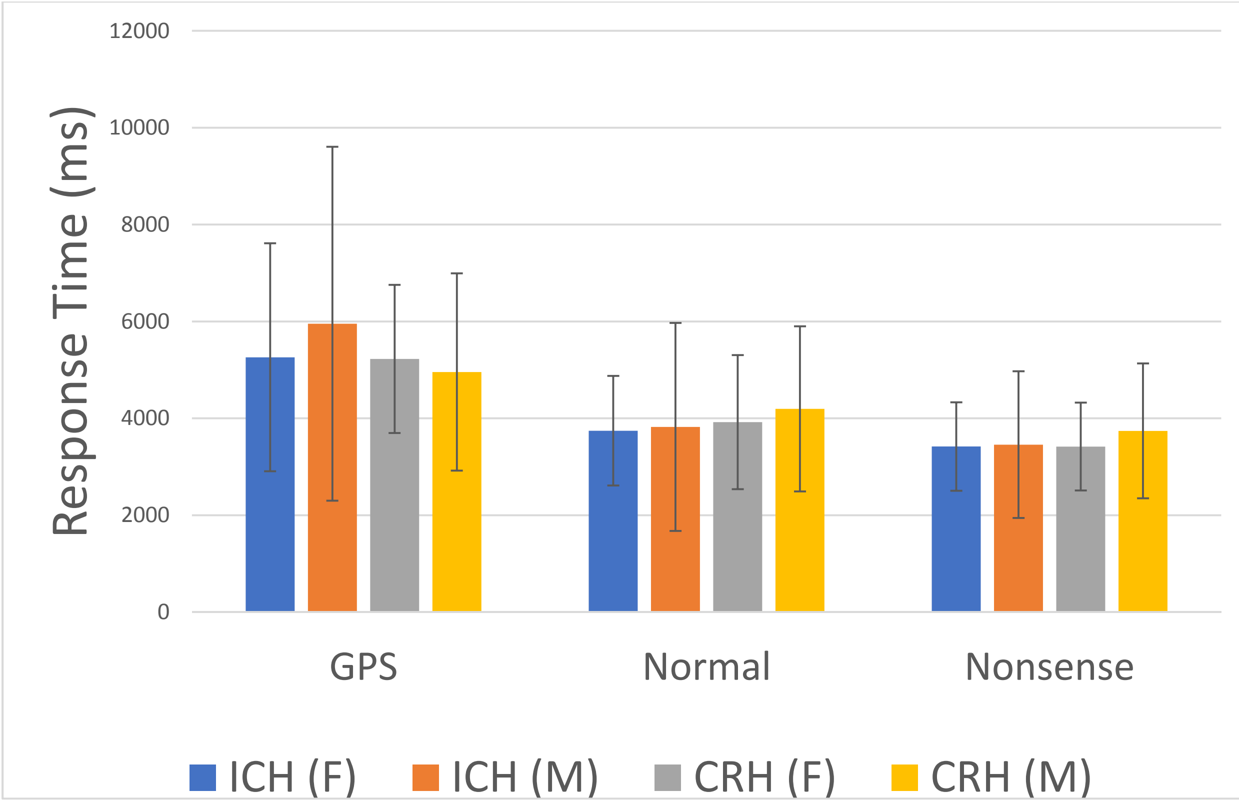

Figure 4. Response time (in milliseconds, RT) by handedness (inconsistent-handers (ICH) and consistent right-handers (CRH)), sentence type (garden path sentences (GPS), normal sentences (Normal), and nonsense sentences (Nonsense)), and gender. Error bars represent standard deviation. Error bars indicate standard deviation.

References

Ambeuhl, S. & Li, S. (2018) Belief updating and the demand for information. *Games and Economic Behavior, 109* 21-39.

Banich, M. (1998) The missing link: the role of interhemispheric interaction in attentional processing. *Brain and Cognition, 36*(2), 128-157.

Barnett, K. J., and Corballis, M. C. (2002). Ambidexterity and magical ideation. *Laterality* 7, 75–84.

Bever, T. 1970. The cognitive basis for linguistic structures. Cognition and the Development of Language, ed. By J.R. Hayes, 279-362. New York: Wiley and Sons.

Broadbent, D.E., Fooper, P.F., FitzGerald, P. & Parkes, K.R. (1982) The Cognitive Failures Questionnaire (CFQ) and its correlates. *The British Journal of Clinical Psychology, 21*(1), 1-16.

Cabeza, R., Kapur, S., Craik, F. I. M., McIntosh, A. R., Houle, S., & Tulving, E. (1996). Functional neuroanatomy of recall and recognition: A PET study of episodic memory. *Journal of Cognitive Neuroscience, 9*, 254–265.

Cahill, L. (2006) Why sex matters for neuroscience. *Nature Reviews Neuroscience, 7*(6), 477-484.

Casasanto, D. (2009) Embodiment of abstract concepts: Good and bad in right- and left-handers.

Journal of Experimental Psychology, *138*, 351-367.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective

responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, 67, 319-333.

Christianson, K., Luke, S., & Hussey, E. (2017) Why reread? Evidence from garden-path and

local coherence structures. *Quarterly Journal of Experimental Psychology, 70*(7), 1380-

1405.

Christianson, K., Willians, C., Zacks, R., & Ferreira, F. (2007) Younger and Older Adults'

"Good Enough" Interpretations of Garden Path Sentences. *Discourse Processes*, *42*(2), 205-238.

Christman, S.D., & Campbell, M. (2013). *Handedness differences in the processing of garden-*

path sentences. Unpublished study.

Christman, S., Henning, B., Geers, A., Propper, R., & Niebauer, C. (2008) Mixed-handed

persons are more easily persuaded and more gullible: interhemispheric interaction and

belief updating. *Laterality, 13*(5), 403-426.

Christman, S. D., Propper, R. E., and Brown, T. J. (2006). Increased interhemispheric interaction is associated with earlier offset of childhood amnesia. *Neuropsychology* 20, 336–345.

Christman, S. D., Geers, A. L., Kosbab, K., and Weiland, P. E. (2006). Placebos and belief updating: Strong right-handers do not show placebo effects. *Presented at the 35th Annual Meeting of the International Neuropsychological Society*, Boston.

Christman, S. D., & Propper, R. E. (2001). Superior episodic memory is associated with interhemispheric processing. *Neuropsychology, 15*, 607–616.

Christman, S., Garvey, K., Propper, R., & Phaneuf, K. (2003) Bilateral eye movements enhance the retrieval of episodic memory. *Neuropsychology, 17*(2), 221-229.

Crow, T., Crow, L., Done, S., & Leask, S. (1998) Relative hand skill predicts academic ability: global deficits at the point of hemispheric indecision. *Neuropsychologia, 36*(12), 1275-1282.

Cummings, J., Benson, D., Walsh, M., & Levine, H. (1979) Left-to-right transfer of language dominance: a case study. *Neurology, 29*, 1547.

Dickson, D. H., & Kelly, I. W. (1985). The ‘‘Barnum Effect’’ in personality assessment: A review of the literature. Psychological Reports, 57, 367-382.

Downing, K. (2009) Gender and cognition. *Proceedings of the Second International Conference of Teaching and Learning*, 1-17.

Drake, R. A. (1993). Processing persuasive arguments: II. Discounting of truth and relevance as a function of agreement and manipulated activation asymmetry. *Journal of Research in Personality, 27*, 184-196

Drake, R. A. (1991). Processing persuasive arguments; Recall and recognition as a function of agreement and manipulated activation asymmetry. *Brain and Cognition, 15*, 83-94.

Faurie, C., Schiefenhovel, W., Le Bomin, S., Billiard, S. & Raymond, M. (2005) Variation in the frequency of left-handedness in traditional societies. *Curr. Anthropol. 46*, 142–147.

Gazzaniga, M. (2005) Forty-five years of split brain research and still going strong. *Nature Reviews Neuroscience, 6*, 653-659.

Gron, G., Wunderlich, A., Spitzer, M., Tomczak, R., & Riepe, M. (2000) Brain activation during human navigation: gender-different neural networks as substrate of performance. *Nature*

Neuroscience, 404-408.

Gorynia, I., & Egenter, D. (2000). Intermanual coordination in relation to handedness, familial

sinistrality and lateral preferences. *Cortex*, *36*, 1–18.

Hardie, S. & Wright, L. (2014) Differences between left- and right- handers in approach/avoidance motivation: influence of consistency of handedness measures. *Frontiers in Psychology, 20,* doi: 10.3389/fpsyg.2014.00134.

Jacob, G. & Felser, C. (2016) Reanalysis and semantic persistence in native and non-native

garden-path recovery. *Journal of Experimental Psychology, 69*(5), 907-925.

Kalat, J. W. (2015). *Biological psychology*. Nelson Education.

Khedr, E., Hamed, E., Said, A., & Basahi, J. (2002) Handedness and language cerebral lateralization. *European Journal of Applied Physiology, 87,* 469-473.

Knecht, S., Drager, B., Deppe, M., Bobe, L., Lohmann, H., Floel, A., Ringelstein, E., & Hennsington, H. (2000a) Handedness and hemispheric language processing in healthy

humans. *Brain, 123*(12), 2512-2518.

Knecht S, Deppe M, Dräger B, Bobe L, Lohmann H, Ringelstein E, et al. (2000b) Language l

ateralization in healthy right-handers. *Brain, 123,* 74–81.

Lane, C., Kanjlia, S., Richardson, H., Fulton, A. (2016) Reduced left lateralization of language in

congenitally blind individuals. *Journal of Cognitive Neuroscience*, *29*, 65-78.

Luders, E., Cherbuin, N., Thompson ,P., Gutman, B., Anstey, K., Sachdev, P., & Toga, A.

(2010) When more is less: associations between corpus callosum size and handedness

lateralization. *Neuroimage*, *52*(1), 43-49.

Lyle, K. B., and Orsborn, A. E. (2011). Inconsistent handedness and saccade execution benefit

face memory without affecting interhemispheric interaction. *Memory* 19, 613–624.

Lyle, K. B., McCabe, D. P., and Roediger, H. L. (2008). Handedness is related to memory via

hemispheric interaction: evidence from paired associated recall and source memory

tasks. *Neuropsychology* 22, 523–530.

Lyle, K.B., Hanaver-Torres, S., Hacklander, R., & Edlin, J. (2012) Consistency of handedness, r

egardless of direction, predicts baseline memory accuracy and memory enhancement.

Journal of Experimental Psychology: Learning, Memory and Cognition, *38*, 187-193.

Malyutina, S. & den Ouden, D. (2016) What is it that lingers? Garden path (mis)interpretations in younger and older adults. *Quarterly Journal of Experimental Psychology, 69*(5), 880-906.

McDowell, A., Felton, A., Vazquez, D., & Chiarello, C. (2015) Neurostructural correlates of consistent and weak handedness. *Laterality,* 1-23.

Niebauer, C. L., Aselage, J., & Schutte, C. (2002). Hemispheric interaction and consciousness: Degree of handedness predicts the intensity of a sensory illusion. *Laterality: Asymmetries of Body, Brain and Cognition, 7*(1), 85-96.

Niebauer, C. L., Christman, S. D., Reid, S. A., and Garvey, K. (2004). Interhemispheric interaction and beliefs on our origin: degree of handedness predicts beliefs in creationism versus evolution. *Laterality* 9, 433–447.

Niebauer, C. L. (2004). Handedness and the fringe of consciousness: Strong handers ruminate while mixed handers self-reflect. *Conscious. Cogn.* 13, 730–745.

Novick, J., Hussey, E., Teubner-Rhodes, S., Harbison, I., & Bunting, M. Clearing the garden path: Improving sentence processing through cognitive control training. *Language and*

Cognitive Processes, 1-44.

Oldfield, R.C. (1971) The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9,* 97-113.

Osterhout, R. & Holcomb, H. (1992) Event-Related Brain Potentials Elicited by Syntactic Anomaly. *Journal of Memory and Language*, *31*, 785-812.

Pritchard, E., Propper, R.E., Christman, S.D. (2013) Degree of handedness, but not direction, is a

systematic predictor of cognitive performance. *Frontiers in Psychology*, *4*(9), eCollection. doi: 10.3389/fpsyg.2013.00009.

Pritchett, B. (1988) Garden path phenomena and the grammatical basis of language processing.

Language, *64*(3), 539-576.

Propper, R. & Christman, S. (2004) Mixed- versus strong-handedness is associated with biases

toward “Remember” versus “Know” judgements in recognition memory: Role of interhemispheric interaction. *Memory*, *12*, 707-714.

Propper, R. E., Christman, S. D., and Phaneuf, K. A. (2005). A mixed-handed advantage in

episodic memory: A possible role of interhemispheric interaction. *Memory and Cognition*, *33*, 751–757.

Propper, R., Patel, N., Christman, S., & Carlei, C. (2017) Superior episodic memory in inconsistent handers: a replication and extension using fNIRS. *Memory*, *25*(10), epub

2017 Mar 31.

Propper, R., Christman, S., Phaneuf, K. (2005) A mixed-handed advantage in episodic memory: a possible role of interhemispheric interaction. *Memory & Cognition*, *33*(4), 751-757.

Ramachandran, V. S. (1995). Anosognosia in parietal lobe syndrome. *Conscious. Cogn.*4, 22–51.

Trehout, M., Leroux, E., Delcroix, N. & Dollfus, S. (2017) Relationships between corpus callosum and language lateralization in patients with schizophrenia and bipolar disorders. *Bipolar Disorders, 23,* 76-89.

Ven Herten, M., Chwilla, D., & Kolk, H. (2006) When Heuristics Clash with Parsing Routines: ERP Evidence for Conflict Monitoring in Sentence Perception. *Journal of Cognitive Neuroscience, 18*, 1127-1140.

Supplemental Figures

Garden Path Sentences
When Fred eats food gets thrown.
Mary gave the child the dog bit a band-aid.
The horse raced past the barn fell.
The man who hunts ducks out on weekends.
The florist sent the bouquet of flowers was very flattered.
The old dog the footsteps of the young.
The woman whistling tunes pianos.
The guilty mover took the drawer over to look at the broken picture frame.
When it rained the sewer overflowed with happiness to sell more raincoats.
The fisherman hung the bass where he could reach it to play every evening.
The cotton clothing is made of usually grows in Mississippi.
The girl told the story cried.
Her date wanted to give the table an evening out since it was lopsided.
The golfer didn't like putting the dog out.
The racer took the lead over to the scrap pile.
She didn't want to resign, but the pen ran out of ink.
The clock had a minute amount of dirt on it.
I convinced her children are noisy.

Nonsense Sentences
The bubbles charging cards all night long.
Alice bought gloves for apples her eyelashes.
The bear purple spotted monkey in the store.
The batteries dancer until dawn went back to bed.
David petting his dog before he clipped its wings.
She parked her car inside the mailbox.
Tom gave the tree his business card.
He burnt his fingers on the raining ice cream sandwich.
The river kept snore and waking up all the waves.
Bob, the gardener, pruning kittens than dogs this year.
Trudy giving hurt blue in envelopes pineapple.
Shirley leaving torn boughs apart told.
He give thorough wash to dog.
They movie was horrible train watched.
Trying hard for speckled eggs turnips.
He packs bag and go trips.
Cheryl call to them and for good at ten or fifty apart.
Bird try hard box them could be none.

Normal Sentences
The circus was only in town for two weeks this summer.
Sarah wanted to go to the zoo to see lions and zebras.
Mona painted her new room in gray and blue.

The car wouldn't start so he walked to work in the morning.
The policeman didn't like coffee with his donuts.
The sunrise turned the sky red and orange.
The music wasn't very good so she changed the channel.
The phone rang twenty times until someone finally answered it.
She put dishes on the table and called everyone in for dinner.
Marcia took her car in for service and got an oil change.
The wind carried the leaves down from the tree.
The child pointed at the red ball.
The city was alight with a myriad of Christmas lights.
Bill was excited to be able to march in the parade in the spring.
Their dog always slept in the sunlight.
Carol went shopping for a dress.
Rachel needed another dime to pay for her sandwich.
Helen told her dad about the car for sale.

Figure 5. Garden path, normal, and nonsense sentences presented to participants for categorization. During presentation, sentences were randomized in Superlab 5.0.5. Adopted with no changes from Christman & Campbell (2013).