HANDEDNESS AS A PREDICTOR OF STARTLE RESPONSE REFLEXES ELICITED DURING UNANTICIPATED DRIVING EVENTS

by

Jennifer S. Seeley

An Abstract
of a thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
in the Department of Psychological Science
University of Central Missouri

May, 2012

ABSTRACT

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Left-handers have been shown to be at a greater risk for collisions and/or injuries while driving motor vehicles than right-handers. Some have suggested that this trend may be due to different response reflexes between left- and right-handers that affect driving behavior, especially those that occur during startling roadway events. To test this hypothesis, we evaluated the role of handedness on startle response reflexes of 30 students at a Midwestern university in terms of its ability to predict drivers' reactions during an unanticipated driving situation. Frequencies for handedness were 14 right-handers, 11 left-handers, and 5 mixed-handers. Results based on observational checklists and video footage analysis indicated that handedness was a significant predictor of specific startle reflexes with right-handers more likely exhibiting a right-hand turn response, left-handers exhibiting a left-hand turn response, and mixed-handers not exhibiting a startle response turn in either specific direction.

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ACKNOWLEDGMENTS

Although this thesis is an individual work, I could never have reached this level of success without the efforts of several people. First, I would like to express the deepest appreciation to my professor, mentor, and thesis committee chair, Dr. Joseph J. Ryan, who guided me through my undergraduate and graduate career at the University of Central Missouri. Without his wisdom and enlightening yet frightening red pen, I would not have developed the background in scientific knowledge, skepticism, and perseverance which I possess today.

Special thanks are due to my thesis committee members and advisors, Drs. David Kreiner and Steven Schuetz for their years of tuition, feedback, encouragement, and patient guidance I have received from them both. I would like to thank Dr. Kreiner specifically for providing his extensive knowledge of statistics and infectious sense of humor during this stressful thesis process. I am indebted to James Delap and his associates at the Missouri Safety Center who provided their facility, automobiles, and large portions of time for the purpose of this research. Thanks also go out to Dr. Scott Strohmeyer, Chair and Professor in the Department of Kinesiology at UCM, for his assistance with the analysis of video footage data.

Many thanks to Sara Thomas and other research assistants for helping me with recruiting participants and collecting research data. I am grateful for your patience and dedication. This thesis would not have been possible without all of your help. Tina Walker, the Office Professional in the Department of Psychological Science, has not only assisted me through my career at UCM but has also been the bearer of my thesis frustration rants.

Finally, I thank my close friends and family for motivating me towards my goals and believing in my successes even when I was doubtful.

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CHAPTER 1
NATURE AND SCOPE OF THE STUDY

Left-handedness is considered a risk factor for traffic-related accidents and unintentional injuries. These collision-related injuries are a growing and preventable predicament within the United States (Lewit & Baker, 1995). Identifying reasons why left-handers have an increased likelihood of being involved in traffic-related accidents is imperative as traffic accidents are cited as the leading and most lethal cause of unintentional injury (Coren, 1989).

Left-handers have a markedly increased susceptibility to unintentional injuries (Coren, 1989, 1990, 1992b; Coren & Halpern, 1991; Graham, Cleveland, & Bonner, 1992; Graham, Glenn, Dick, Allen, & Pasley, 1992; Janssen, 2004; Lewit & Baker, 1995). These injuries induce pain and affect many facets of life, leading to an indirect negative impact on the U.S. economy. With the current financial state of the government, officials are making every attempt to reduce factors that may be causing undue harm to its citizens. By identifying causes of unnecessary burden, the threat to individuals' well-being may be decreased and ultimately eradicated.

The leading and most lethal cause of unintentional injury is motor vehicle-related, accounting for over 44% of all unintentional deaths in the nation (Coren, 1992a). Traffic-related injuries account for more than 60% of potential life years lost before age 65 and are the leading cause of unintentional death for people between the ages of one and 74 years of age. In relation to handedness, driving is the single highest risk situation for male left-handed drivers (Coren, 1989; MacNiven, 1994). Combined, male and female left-handers are 85% more likely than right-handers to sustain a traffic-related injury (Coren & Halpren, 1993). Coren (199b) postulated a difference in reflex responses between left- and right-handed individuals that might explain this increased susceptibility.

According to Coren (1992b), inconsistent response reflexes between left- and right-handers while operating a motor vehicle, especially following an unanticipated driving event, could assist in explaining the increased likelihood for left-handers to report a history of motor vehicle collisions. Coren goes on to state that if left-handers are startled by an abrupt event while driving, such as a deer darting out in front of the vehicle, that an ingrained reaction response will likely cause them to steer the vehicle in the left direction. In America, this left-turn propensity could be detrimental in that, depending on the roadway system, could direct the vehicle into oncoming traffic or a cement block median. In contrast, Coren (1992b) postulated that a right-handed driver who is faced with the same startling event would react in an opposite way, steering the vehicle to the right side of the roadway which, in many cases, would direct him or her into a ditch, another lane, or shoulder of the road.

To date, Coren's hypothesis has not been tested using drivers in an actual driving situation. Although several studies have cited left-handers' disposition for left-sided startle reactions (e.g., Coren, 1992a; Coren, 1992b; Daily Telegraph, 2004), none have attempted to observe differences in reflex responses of left- and right-handers while actually operating a motor vehicle. By discovering if there is in fact a differential startle response reflex between drivers with different lateralities, researchers could provide useful information to decrease the likelihood of motor vehicle accidents on American roadways. Observing behaviors during driving and including a stimulus which would likely induce a startle reflex in drivers operating a motor vehicle could potentially provide a better understanding of the current data regarding left-handers and their reduced level of driving proficiency as compared to right-handers.

The present study attempts to investigate the hypothesis suggested by Coren (1992b) which states that right- and left-handed drivers have differential startle response patterns during an unanticipated driving event. Significant differences in the hypothesized direction and degree of turns for right- and left-handed drivers would provide support for handedness as a predictor of driving performance. If handedness reliably predicts how drivers respond to startling events during the operation of a motor vehicle, this might have an impact on how to best train drivers who are left hand dominant, and encourage state motor vehicle departments to collect handedness data on all persons issued a driver's license. If state motor vehicle departments routinely collect handedness data it will allow for future research concerning the role of left handedness in accidents in general and head-on collision in particular.

CHAPTER 2
REVIEW OF LITERATURE

Handedness

Handedness (also referred to as laterality, side bias, hand preference, and hand dominance) is defined as the disproportionate distribution of fine motor skill between the left and right hand (Raymond & Pontier, 2004). Right-handers (also known as dexterous or dextral individuals) are those that are more skillful with the right hand, whereas left-handers (sometimes referred to as sinistrals) are more competent with the left hand. Ambidextrous individuals are equally adept with both the left and right hand, and are sometimes referred to as being mixed-handed, inconsistently-handed, or cross-dominant. Because handedness has predominantly been recognized as the hand chosen for writing, ambidextrous individuals have been historically underreported and their actual handedness base rates are undetermined. Currently, there is no gold standard for measuring laterality and the criteria for hand dominance varies across regions, leaving a universal measurement approach and accurate base rates for handedness unavailable.

Most humans have a general tendency to use their right hand as opposed to their left hand for uni-manual tasks (Harris, 1990; Peters, 1995). This right-handed preference has been a universal trend throughout recorded history (Coren, 1992b; Hardyck & Petrinovich, 1977). Current base rates of right-handedness are between 70% and 90%. Nevertheless, a small proportion of the population maintains a left-handed preference. Left-handers are estimated to currently comprise between 5% and 30% of the population worldwide (Coren, 1992b), with proportionately more men than women being identified as left-handers (McKeever, 2000; Oldfield, 1971). The incident rate of nine right-handers for every one left-hander has remained steady for more than a century (Porac & Coren, 1981).

At present, the rate of left-handedness is disproportionate within different cultures around the world (Perelle & Ehrman, 1994). Some postulate that this variation is due to biological and/or developmental determinants, but primarily the inconsistency is ascribed to the inverse affiliation existing between socio-cultural pressures and left-handedness (Ida, Dutta, & Mandal, 2001). These pressures have been linked to religious beliefs which assigned disparate connotations to the left and right hand. In countries with high pressures, such as China and India, the frequency of left-handers is much lower in comparison to countries with weak or even nonexistent sanctions against left-handedness. Countries with these comparatively lax pressures, such as the United States and Belgium, report much higher rates of left-handedness in the population. These discrepancies will be discussed more in depth shortly, but first let us understand the historical examination of handedness, ranging from religious perspectives to linguistic connotations.

Historical Representation

Left- and right-handers have coexisted since Paleolithic times, and artifacts from the Stone Age show no lateral preference for hand usage. Tools used during the Stone Age were appropriately fit for either hand, and artistic representations during that time show men using both hands for activities such as hunting, fishing, and tool-making (Blau, 1946). It was not until the Bronze Age when a clear preference for right-handed use was identified. Several theorists have attempted to explain this trend, but none have been able to find significant empirical support for specific explanations. Some postulate that development of the dominant right hand was caused by sun worship. Others have reasoned that laterality was an effect of hunting methods. With the right hand used for carrying hunting weapons, the left hand was free to hold a shield for protecting the heart. Apparently, primitive men knew that the heart is positioned in the left side of a man's chest so holding a shield in the left hand would provide protection for the heart. The preferential use of the right hand for deploying weapons may have carried over into the adeptness for using the right hand with tools. Since these tools were made of metal, and the process of making these tools was long and strenuous, many families would pass down their tools through generations (Blau, 1946). And since many of these tools were made to fit the right hand, descendents of familial predecessors often had to use their right hand to use the tools they inherited.

Social pressures may have been another possible reason that right-handers emerged as the dominant laterality group. Theorists have hypothesized that societies attempt to prevent the unnecessary reproduction of devices in order to conserve money and energy that may be spent on more useful items. Such efforts may be an attempt to increase the sophistication of a society's individuals, and inadvertently shape their behavior into becoming more civilized (Blau, 1946). This is not a universal trend, however. In Ancient China, the right and left hand were thought of as complementary to one another, with neither hand being superior to the other (Costas, 1996). Of course these views have changed over time, but it is serene to imagine a time in China when laterality was analogous and not competitive.

Left-Handedness and the Bible

Handedness, and more particularly left-handedness, has been documented throughout history, and several citations in the Christian Bible allude to negative associations of left-handers. Many of these passages address God specifically in their reference to handedness, and the destiny of those that sit on either the left or right side of the Deity. Looking at the Book of Psalms in the Old Testament, the Lord's right hand is designated as just and "full of righteousness" (48:10; Joint Committee on the New Translation of the Bible, 1970). Later again, Psalms proclaims that "[God's] His right hand shall hold me" (139:10). These virtuous testimonials of the right hand are not limited to the Book of Psalms, and in fact, more than 80 references to right handedness are made throughout the Bible; all of them speaking about the right hand's morality, honor, and supremacy. By contrast, the left hand is awarded few accolades. The Book of Ecclesiastes asserts that the right hand holds the hearts of wise men, while the left hand holds only the hearts of fools. In fact, the majority of relevant Bible passages are similar to this one in respect to the calamities carried in the left hand. Many passages state that those at the left side of God are destined for anguish and retribution. An example of this is seen in the Book of Matthew in the New Testament (Joint Committee, 1970), which states:

> "Then He will say to those on his left hand, 'the curse is upon you; go from my sight to the eternal fire that is ready for the devil and his angels'" (Matthew 25).

Though Biblical language is ambiguous in its regard for the left-handed minority, the Bible shows strong implications for suspicion of deviance in those with such a preference. "Let not thy left hand know what thy right hand doeth" is a notorious Bible verse, giving the impression that the left hand is wicked and must be kept oblivious to the plans of the ethical right hand. These references have been used throughout history to support the notion that anyone with a left-handed preference should be suspected of deviance and heresy.

The Left Hand of Satan

Traditionally, evil and devils have been linked to the left side of the body (Coren, 1992b). Interestingly the word Satan, a common English phrase for the Devil, in is no way connected to the left through is derivation. It translates from the Hebrew as meaning "opponent." The Talmud however, a collection of Jewish oral laws translated from Hebrew language, refers to Satan as Samael. This word is closely linked with *se'mol*, the Hebrew word meaning "left side".

According to the Talmud, the angel Michael sits on the right side of God and Samael on the left. Following Samael's expulsion from Heaven, he is replaced by Gabriel (Costas, 1996). It is interesting to note that Gabriel does not carry with him the same stigma of the left side (other than perhaps having the ordained job of announcing the apocalypse).

Among various cultures, the assignment of good and evil to the right and left, respectively, is present. One example is seen in the Maori tribe of New Zealand. According to Coren (1992b), the Maori believe influences that are life-giving, helpful, and rejuvenating enter from the body's right side, while death and misery infiltrate into the body from the left side. If the belief in most cultures is that the left is evil, then it makes sense that evil deeds are thought to be done with the left hand. To elaborate further, it could be easily assumed that all evil people are left-handed and that even the Devil himself, Satan, is a left-hander. Anthropologists have identified examples of this belief in Eskimos whom, throughout history, viewed left-handers as possible wizards (Hertz, 1909; as cited in Coren, 1992b).

In Ancient Rome, many believed that a man's left side was secondary to the supremacy of his right. In Ancient Rome, all togas bore a pocket on their left side, and "sinus" was the word for pocket; from this, the word sinister was derived (Bliss & Morella, 1980). When saluting, Roman men would gesture with their right hand and when marching or entering a building, would step with their right foot. Consequently, the last part of the body to enter a building was the left or sinus side. In time, the left side became associated with clandestine and devious acts (Costas, 1996).

Due to religious documents and spiritual beliefs, cultures began to develop terms and definitions for the left and the right side. In addition to the denotation of laterality, these words eventually began to assume denotations of human character. As may be expected, expressions of the right side became indicative of positive attributes, whereas left was used in reference to lesser and more negative descriptions. In the next section, we will explore handedness and its use in different languages. From single words to slang references and nicknames, the abundance of perspectives regarding laterality will hopefully be made apparent.

Linguistic Discrimination Against the Left

Left-handers are commonly discriminated against through the use of language (Coren, 1992b). Take the English word left; a derivative of *lyft*, the Anglo-Saxon word meaning “frail” or “broken.” The Oxford Dictionary (1989) even cites left-handed as something or someone that is “crippled,” “defective,” “awkward,” “clumsy,” or “inept.” Synonyms for right appear to be much less abrasive and include the following: appropriate, equitable, scrupulous, normal, and roughly thirty more comparable terms (thesaurus.com). The animosity towards left-handers is not exclusive to the English language, but appears universally. “Dexterous,” the Latin word for “right” suggests proficiency, yet the Latin word “sinister,” was (and still is) used to indicate abnormality and deficiency. The Romans decision to use such an unflattering word for left was deliberate and used as a reminder of the left side’s immorality. Since all of the Romance languages - including French, Spanish, and Italian - are Latin derivatives, they too contain the same biases of the left and right side. The Italian disparagement against the left-hander is a historical remnant of the Latin word, *sinister*. This word is closely related to *sinistrum*, the noun which means evil. In the English language, sinister is often used to describe something that is menacing, hopeless, scary, evil, or satanic (Coren, 1992b). Yet even languages such as German, which did not descend from Latin, still express awkwardness and dishonesty with words that simultaneously describe the left side.

If we look at Western Europe, the French use the word *gauche* for left, yet it also conveys being “crooked,” “ugly,” “uncouth,” and “bashful.” When *gauche* is directly transferred to English, it bears the same negative suggestion. To call someone a “gauche” is to say that he or she acts inappropriately in public (Coren, 1992b). The French word for right however, *droit*, is also used to say that something is “right,” “straight,” and “just.” *Linkisch*, the German word for left-handed, has an adverse dictionary definition of “awkward” and “maladroit,” whereas *recht*, the word for right-handed, is also used to express truth. It is common for German words to appear almost identical to words used in the English language, and not inadvertently. When the German tribes invaded England around 500 AD, they strongly influenced the English language. Many believe that it was the Germans who triggered the shift for left to insinuate frail and meaningless in English (Fincher, 1977). Today, a quarter of the words used in the English language were directly influenced by ancient German vernacular, with the remaining percentage being constituted mainly of French and Latin derivatives (Taube, 1940).

The left-hander is not spared from slander in Spanish, where left-handed is given the word *zurdo* meaning “malicious.” A phrase like *no ser zurdo*, meaning “to be cruel,” translates in English as “not to be left-handed.” A left-handed Italian is *mancino*, a derivative of *mancus* meaning maimed. With the meaning of these words continuing in wide use, it implies a general acceptance for the antagonistic idea of the left-handed population by those speaking the language. Thus, our languages portray left-handers as being undesirable and troublesome.

Today the English language possesses several common phrases boasting a negative opinion of left-handedness (Coren, 1992b). For example, to give someone a *left-handed compliment* is actually to serve him or her with an insult. A child from the *left side of the bed* is illegitimate. A collection of errors is known as *left-handed wisdom*, and a doctor’s inaccurate medical decision is known as a *left-handed diagnosis*. When sailors describe ships that are left-handed, they are making a reference to the ship's misfortune or "irregularity." Homosexuals have long been tagged as left-handed; someone saying that a man is *bent to the left* carries the same connotation (Coren, 1992b).

It is nearly impossible to find a single positive phrase in the English language targeted at being "left" or "left-handed." Conversely, *right* and *right-handed* rarely connotes anything more than an individual's preference for carrying out tasks and activities. A *right-handed wife* is simply a spouse who favors her right hand. In the rare instance when right does seem to carry with it any emotional content, it appears to carry a positive one. To be someone's *right-hand man* is to have a position of importance to the person in question (Coren, 1992b).

Several slang words exist for left-handedness. "Molly-dooker," is a slang word used in Australia denoting someone who is left-handed. Molly, is the word meaning woman or sissy and dooker describes a fist, so translated molly-dooker means "sissy-fisted" or someone who "fights like a girl" (Bliss & Morella, 1980). In Germany, the term widdershins or withershins, meaning "against the journey of the sun," is the name assigned to sinistrals. This stemmed from the view that the sun appears to rotate clockwise when facing to the south. Since left-handers were thought to operate in a way opposite of right-handers, the idea sprang that left-handers move opposite of the sun (Silverstein and Silverstein, 1977).

Although almost all nicknames hold an anti-left sentiment, one name does not - "southpaw." This term was originally coined by Charles Seymour, a Chicago sportswriter in the late 1800s. During a major league baseball game, Seymour was commenting on a left-handed pitcher. The stadium in which the game was being played was built in order to keep the sun from shining in the batter's eyes. As a result, the pitcher faced south or southwest depending on which arm he used to throw the ball. If using the left arm, the pitcher would position his body so that his throwing arm would be directed to the southern side of the stadium. Since a radio audience did not have a visual representation of the players, and Seymour wanted to help listeners visualize the game, he started using the term southpaw in order to indicate when a left-handed pitcher was on the mound (Fincher, 1977). Today all left-handers, not just baseball pitchers, are referred to as southpaws.

Beliefs and myths of left-handers, whether bad or good, have integrated themselves into all cultures. These opinions often lack validity and empirical support from the scientific community. What is apparent is that these historic myths have sprouted a curiosity about left-handedness and its origins. Theorists have postulated the ontogeny of handedness for centuries, drawing from several different areas in order to form causal theories. Let us now look at some of these approaches and the ways in which each of them attempts to explain the formation of handedness.

Historical Approaches to Handedness

Historically, two main approaches were thought to explain the formation of handedness. The most common approach was the assumption that left-handedness was an external signal of an internal abnormality-that it was representative of some bodily dysfunction, thus being excluded from theoretical input of normal cognitive functioning. Copious amounts of research have examined this notion, but findings in support of this idea remain limited and unreliable. A divergent position of this approach suggested that left-handedness was an evolutionary retrogression (Levy, 1969; Miller, 1971; Nebes, 1971) - a genealogical track backward.

The second historical approach simply disregarded the left-handed population, ignoring any and all observed differences between them and the right-handed majority, and/or assuming that left-handed functioning was a "simple mirror image" of the right-handed majority (Hardyck & Petronovich, 1977). In 1861, Paul Broca was the first to propose this mirror image hypothesis, and was immediately met with case reports preventing his idea from ever being considered consummate. Amazingly, this mirror image belief endured in the medical and neurological literature until roughly 1936, with some still holding steadfast to this theory (Sperry, 1973). Broca did however discover a relationship between right-handedness and left-hemispheric brain specialization for language abilities. Unfortunately, the association between the brain and handedness is neither simple nor consistent. Research conducted in the 1970s found that most strong left-handers have language specialization in the brain's left hemisphere, typical for 95% of right-handers. Only 38% of left-handers have atypical patterns of hemispheric brain specialization (McKeever, 2000).

Introductory attempts to understand handedness were primarily rooted in the philosophical belief that left-handedness was indicative of abnormality and deficit. Although some of these early discoveries were intellectually stimulating and useful, many were simply attempts to support societal expectations. Advances have since been made, and although there is much still left to discover, today's theories of handedness formation are supported by a foundation of empirical support. What is clear is that scientists are fascinated with the left-handed minority; not only with their adaptive traits but also with their biological, neurological, and continued and consistent expression in roughly 10% of humans.

Theories of Left-Handed Acquisition

Hand dominance is the most widely studied form of lateralization (Alibeik, Angaji, Pouriamanesh, & Movallia, 2011). Theories of handedness causation are plentiful in the literature, with the majority of historical beliefs being dismissed by today's empirical evidence.

Today's research tends to support a genetic ontogeny yet with the incidence of hand preference still being extremely variable, there are still questions that remain. This section will present the three main approaches of handedness acquisition- genetic background, socio-cultural pressures and environmental influences, and pathological determinants.

Genetic Factors

The recording of the transmission of handedness from parent to offspring was the first attempt to characterize specific mechanisms involved. Two parents with right-handedness are less likely to produce a left-handed child than any other handedness combination, with two left-handed parents producing the highest percentage of left-handed offspring, i.e. roughly 30-40% (McKeever, 2000). This suggests that through either genetics of learning, hand preference may be quite possibly transmitted through a familial link.

Left-handedness in children is more likely to occur than right-handedness when the mother is left-handed and the father is right-handed (Francks et al., 2007; McManus, 1991), suggesting that maternal effects are stronger for the handedness determination of offspring. Molecular studies of handedness involving genome-wide approaches have suggested that specific regions of the X chromosome may influence one's manifest handedness, based as part of a sex-linked genetic effect, of either the left or right hand (Francks et al., 2007). According to Francks, LRRTM1 (Leucine-rich repeat transmembrane neuronal 1) is an imprinted, maternally-suppressed gene. This is consistent with previous theories suggesting an X-linked determinism. McKeever (2000) made an interesting observation regarding this X-linked trait, noting an effect for only male, and not female, offspring. Current heritability projections of left-handedness in both males and females as a result of the presence of the LRRTM1 gene range from .23 to .66 (Porac & Coren, 1981; McKeever, 2000).

The vast majority of genetic theories of handedness, and more specifically, left-handedness, assume that familial handedness is positively correlated to direction and degree of handedness (Annett, 1975; Levy & Nagylaki, 1972; McKeever & VanDeventer, 1977; Trankell, 1955). Also these views vary in evaluation of handedness, they are similar in that they use a genetic model in order to explain the transmission of handedness from parent to offspring. Although these theories are empirically supported, there are three remaining problems interfering with the etiology of hand preference: (i) socio-cultural influences on hand usage, (ii) even with identical genotypes, monozygotic twins are still divergent in their handedness by 18%, and (iii) only 30-40% of children from two left-handed parents are they themselves left-handed. Generally speaking, most models are dependent on the assumption that a genetic bias is influential for laterality (Annett, 1975; Levy & Nagylaki, 1972; McManus, 1991). Historical views such as the Mendelian model fail to fit current data.

Typically, models propose that a specific gene is the primary influence for handedness. Most influentially, the "right shift theory" proposed by Annett (1975) is based on the notion of a single gene with two alleles. Being that this model allows for chance factors and environmental influences during development, it sets a 50% threshold for the proportion of left-handers in a population. By doing this, it allows for explanation of the small number of left-handed children produced by two left-handed parents and explains the problem of discordant handedness in monozygotic twins. Although other theorists propose genetic models with additional alleles (i.e., McKeever, 2004), Annett's model appears to be most widely accepted. Unfortunately, these models do not accommodate all observations of handedness, and thus indicate that a genetic factor for handedness may consist of several genes and/or unknown variables.

Studies based on familial transmission of handedness and empirical data have indeed shown that handedness is significantly influenced by genetics. To further explain the intricate pressures pertaining to this trait, we will now focus on environmental and pathological factors involved in hand preference.

Socio-cultural Influence

The environment has been shown to significantly influence the expression of left-handedness in individual societies and worldwide. It was Laland et al., (1995) who criticized the current genetic models stating that despite the copious evidence in support of cultural influences, genetic theorists did little to incorporate this idea into their models. Attitudes towards left-handers vary throughout history and by culture (Costas, 1996; Hardyck & Petrinovich, 1977). There are three primary ways in which cultural and environmental facts could change handedness, and these factors vary by the type and degree of pressure involved: (i) forcefully changing the hand used for activities such as writing, while not affecting hand preference for other uni-manual activities, (ii) shifting towards a more mixed hand dominant population, or (iii) applying strong pressure to all activities performed with a hand, thus changing the overall preferred hand.

i. The frequency of left-handed writing was noted to steadily increase during the late half of the twentieth century (Dellatolas et al., 1988). This was noted as a ‘generation effect’ and has been since observed in other countries such as Italy (Salmosa & Longini, 1985). In China and Taiwan, the proportion of schoolchildren using their left hand for writing is only 3.5 and .7%, respectively (Teng, Lee, Yeng, & Chang, 1976). By comparison, Asian children living in the United States have an increased rate of left-handedness at 6.5%, indicating that cultural pressures to be right-handed in America are reduced (Hardyck, Petrinovich, & Goldmann, 1976). In some countries, the pressure to use the right hand is more severe. The Kaffirs of South Africa would immobilize the left hand of child by burying it in the desert's burning sand in order to leave it ineffectual (Durr, 1979). Still today, children in Indonesia have their left hand bound in order to discourage its use (Fincher, 1977). Perhaps the most brutal form of environmental pressure comes from Japan prior to World War II. There, left-handed children were beaten; left-handed men were revoked of all social, financial, and political rights as given to them by their social class; and any woman who was left-handed was considered unmarriageable. If a woman was clever enough to mask her sinistrality until after marriage, then her husband had the right to divorce her based on her secret.

ii. In an observation by De Agostini, Khamis, Ahui, and Dellatolas (1997), those individuals with weak handedness were more likely to report earlier injuries which required them to temporarily shift their hand use to the non-preferred hand. An example of this would be seen in a child who broke his or her wrist which in turn prohibited the child from using that chosen hand for writing. While the injury healed, the child was forced to use its non dominant hand for writing and eventually switched to that hand as the dominant hand for writing. Also, positive reinforcement for using the right hand has been shown to modify patterns of handedness as well as shift the preference of hand being used for different tasks (Bryden et al., 2005).

iii. Although environmental and genetic influences assist in explaining handedness, there are still other possible reasons for the formation of the left-handed minority. Let us now look at the third main approach – pathological handedness based on pre- and perinatal complications.

Developmental Influences

Left-handedness has been linked to a variety of disorders that are resumed to result from some developmental abnormality. These include schizophrenia (Yeo and Gangestad, 1993), mental retardation, autism, and many other medical and/or psychological conditions (Janssen, 2004). Research suggests that birth stress and pregnancy complications, if mild enough, may cause a minor abnormality in cognitive development and is marked by the behavioral expression of left-handedness (Coren & Searleman, 1990). Others have postulated that the age of the mother is a factor is determining offspring's handedness, with older women being more likely to give birth to left-handed children (Coren & Searleman, 1990).

Some theorists have explained the occurrence of left-handedness as an indicator of brain injury. Researchers have postulated that the proportion of left-handers without a genetic predisposition for sinistrality may have acquired a left-handed preference because of a syndrome caused by a perinatal brain injury (Fox, 1985; Satz, 1972; Orsini & Satz, 1986). This syndrome, known as pathological left-handedness (PLH), is due to early left-hemispheric brain trauma which results in a right-to-left switch in hand dominance. This syndrome was originally identified after researchers noted several case studies of persons with known/suspected brain trauma who were also expressing a left-handed preference. Analysis of these case studies showed that these individuals were not only brain-injured and expressing a similar left-handed preference, but were also displaying parallel deficits in particular areas of cognitive functioning. Based on these observations, Orsini and Satz (1986) presented a number of features which were indicative of PLH that include the following: atypical or right hemispheric language specialization; motor impairment of the right hand; impaired visuospatial abilities as compared to verbal comprehension aptitude; and decreased or similar likelihood of familial left-handedness as compared to normal right-handers.

Birth stress

Birth stress defines an array of complications but can include the following: premature birth, elongated labor, breech delivery, maternal age, and multiple births. Left-handedness has been attributed to perinatal left-brain trauma resulting from an oxygen deficiency from some birth stress. Bakan (1971) argues that the change in handedness from right to left may be a residual effect of birth stress. Many have supported his argument, citing the multitude of left-handed individuals with a history of birth stress (Coren, 1992b, 1995b; Coren & Porac, 1980; Coren & Searleman, 1990; Ellis & Pechham, 1991) as well as various types of cognitive impairments.

Coren and Porac (1980) indicated that left-handed children were more likely to have mothers that conceived later in life. Smart et al. (1980) supported this finding after observing that mothers over the age of 39 years were more likely to give birth to left- rather than right-handed children. Furthermore, the rate of concordance for handedness in monozygotic twins is comparatively higher than in dizygotic twins (Sicotte, Woods, & Mazziotta, 1999). This could potentially be explained by in utero conditions present with multiple birth pregnancies.

Genetic, environmental, and pathological components have all contributed to the explanation of hand preference. What is certain is that some selective force is maintaining this lopsided distribution of right- and left-handers. Being as the majority of humans in the world assume a right-handed preference, most designs meant to aid in everyday functioning are suited for the right-hander. Before we discuss the adaptability and functioning of individuals with various lateralities, we must first understand how handedness is classified.

Measuring Handedness

Several methods are used to classify individuals as being right-, left-, or mixed-handed. This classification system is controversial and tests available for handedness identification are as numerous as they are diverse. Currently hand preference and hand performance are the two main measures for assessment, and both may be used to classify individuals into different handedness groups. Preference tests, which are often in questionnaire format, allow for handedness to be subjectively reported based on uni-manual tasks. According to the literature, hand preference questionnaires are the most widely used yet these measures are often criticized based on their high level of subjectivity and lack of consistent reliability (Brown, Roy, Rohr, Snider, & Bryden, 2006). Performance measures however, afford a more objective approach in measuring handedness and require individuals, not to simply report which hand he/she uses, but to carry out specialized tasks with one or both hands (Bryden, Pryde, & Roy, 2000). In some instances, both the preference and performance measures are used to assess an individual's direction and degree of handedness, but linking these two assessments is challenging based on the underlying factors of each type of analysis.

Based on the ease of administration, hand preference questionnaires are commonly used to differentiate individuals into different handedness groups (Bryden et al., 2000). However, results from these measures should be perceived with caution because of the inherent subjectivity contained within such speedy tests. Hand preference questionnaires rely on an individual's interpretation of the questions contained in the test as well as capacity to imagine oneself performing the particular activity. When administered to special populations such as young children or elderly persons, these subjective measures lack consistent reliability. This is due to the potential limits for people in these populations to not only remember the hand used for specific tasks but also the limited aptitude to recall whether or not a specific hand is used for particular circumstances (Bryden et al., 2000). By comparison, hand performance measures allow for greater objectivity and reliability of handedness assessment, but require a larger expenditure of time and resources in order for proper administration. Despite these apparent advantages, self-report hand preference measures are still the most popularly used measure of handedness because of their simplicity and the fact that they can be administered to large groups. Handedness measured by performance on specific tasks (e.g., writing, throwing a ball, etc.) required one-on-one individual administration.

Brown et al. (2006) proposed combining elements of both reported preference and performance measures into one single test for handedness, thus eliminating some of the subjectivity of strict preference measures yet is still relatively brief in its administration time. In their analysis, they found the Wathand Box Test (WBT) to hold the highest reliability for hand performance. In this test, individuals are asked to complete a number of tasks including throwing a ball, playing with a toy hammer, etc. Based on comparisons with hand preference tests, researchers found the WBT was most highly correlated with questionnaires that asked similar questions as those contained in the WBT (Brown et al., 2006). This is not surprising due to the fact that hand performance measures such as the WBT are based on the execution of individual tasks, and these tasks are commonly assessed using hand preference questionnaires. Based on this finding, it would be expected that hand preference measures containing similar items to those tasks assessed in performance tests would similarly classify individuals into handedness groups. Despite this correlation, it is still strongly suggested that performance measures be the primary tool for handedness classification (Brown et al., 2006; Bryden et al., 2000). This is based on its clinical accuracy, reliability, and utility in various populations.

Consequences of leaning to the left

Left-handers face the disadvantage of having to adapt to a mainly right-side dominant world. Most countries produce household tools, construction equipment, vehicles, and even traffic designs that are intended for the safety and convenience of right-handers. This right-handed equipment is often uncomfortable and/or difficult for the left-hander to use, requiring the individual to either develop mixed-hand traits or simply adapt to the inconveniences. If left-handers are unable to adapt effectively to the "right-fit" world, the results often include injury and death.

According to Coren (1989), unintentional injuries occur more often among left-handers than right-handers. Unintentional injuries are those without purposeful intent and include the following: motor vehicle collisions, auto-pedestrian encounters (the leading cause of unintentional injury), bicycle crashes, falls, and occupational injuries (including both those acquired in work and/or home settings). Unintentional injuries affect everyone, but particularly left-handers, and can often have dire consequences. Many people equate injuries that are unintentional with terms such as *accidental*, *accident-related*, or simply *accidents*. Recently, the term *accident* has cited as a misnomer for unintentional injuries because of its implication of unpredictability and one's lack of control over the circumstances surrounding the event (Lewit & Baker, 1995). The National Center for Injury and Prevention Control (NCIPC) ceased using the term *accident* because it believed that it reinforced the notion that injuries were not preventable when, in fact, the likelihood of injury could be reduced using several, often simple, strategies. Unintentional injury is the overall leading cause of hospital emergency admissions in the United States (Halpern & Coren, 1993; Peterson & Roberts, 1992), with more than 28 million people annually seeking emergency care. In 2007, the National Safety Council (NSC, 2010) reported that 34.2 million Americans-- approximately 1 out of 9 people-- sought medical attention due to accidental injury.

Fatal unintentional injuries have become the fifth leading cause of death in the United States, preceded only by heart disease, cancer, stroke, and chronic obstructive pulmonary disease. For people between the ages of one and 44 years, unintentional injuries are cited as the top killer, with more potential life years lost to such events than to cancer (NSC, 2010). Geriatric individuals however, are disproportionately affected by accidental injury. In the United States, only 13% of the population is 65 years of age and older, yet the elderly account for 26% of deaths and 30% of hospitalizations due to unintentional injury (Centers for Disease Control and Prevention [CDC], 2007).

A report from the NSC (2010) reported that unintentional injury-related death, in relation to the average lifespan, assumed an average of 36 life years lost as compared with 16 years with terminal cancer and 12 years for heart-related disease. The number of fatalities in 2007 due to unintentional injuries reached 123,706 or 41 deaths per 100,000 in the population; this can be compared to the lowest annual total on record of 86,777 unintentional deaths in 1992, or roughly 34 deaths for every 100,000 persons (CDC, 2010). Between 2008 and 2010, the annual unintentional injury-related death rate increased by 3%, displaying an undesirable rate variation. Many experts are concerned that if this trend continues, the death rate for unintentional injury will surpass previous records.

Impact of Unintentional Injuries

The economic impact of unintentional injuries and deaths in the United States has created a financial burden. According to estimates by the NSC (2010), the rate of annual unintentional injury and related deaths cost the nation $701.9 billion in 2008, or roughly $2,300 per capita; this estimate includes wage and productivity losses, medical expenses, and motor vehicle damage. These costs are assumed by every individual or household, whether paid directly out of pocket, through increased prices for goods and services, or through raised taxes.

Although many injuries that are categorized as being unintentional, the leading and most lethal cause is motor vehicle-related. Motor vehicle-related injuries are responsible for over 44% of all unintentional deaths in the nation. These injuries account for more than 60% of potential life years lost before the age of 65 years, and are the leading cause of unintentional deaths for people between the ages of one and 74 years. The direct medical care costs attributable to motor vehicle-related injuries totals roughly $6.6 billion annually, with the indirect costs of lost wages and economic productivity amounting to more than $13.4 billion. Additionally, research on the costs of motor vehicle collisions as a proportion of the U.S. gross national product (GNP) has indicated that crash costs constitute approximately 2.0-2.3 percent of the GNP (Blincoe et al., 2002; Elvik, 2000; as cited in Naumann et al., 2010). This percentage is proportionately higher than those found in countries such as Great Britain and Sweden, where annual costs of vehicle-related collisions comprise only 0.5 and 0.9 percent of the GNP, respectively (Elvik, 2000; as cited in Nauman et al., 2010).

The World Health Organization (WHO, 2009) reported that collision-related injuries were the ninth leading cause of death worldwide, and by 2030 is anticipated to become the 5th leading cause of death, outranking HIV/AIDS, diabetes, and heart failure. In June 2009, a WHO report examined traffic-related injuries as a global epidemic and provided road traffic injury estimates and assessments of road safety for 178 countries. The report revealed that the United States had fallen far behind the road and traffic safety improvements of many other countries. These countries, belonging to the Organization for Economic Co-operation and Development

(OECD) and including France, Canada, and Australia, at one time displayed similar traffic death rates to the U.S. during the early 1980s, but have since made substantial developments in decreasing the number of lives lost on their roads. Since the early 1980s, many of these nations have reduced their death rates by more than 60 percent (WHO, 2009). However, the United States continues to experience higher death rates, reducing rates by only 35 percent.

Left-Handers Increased Susceptibility

Extensive research has suggested an association between susceptibility to unintentional injury and left-handedness (Aggleton, 1993; Coren, 1989; Coren & Halpern, 1991; Sskalkidou et al., 1999). Left-handers are more likely than right-handers to report having previously obtained injuries in more than one category (i.e., motor-vehicle collisions, auto-pedestrian encounters, etc) of unintentional injury (Coren & Halpern, 1991). This increased risk has assisted in explaining the reduced lifespan of left-handers as compared to the right-handed majority (Aggleton, Kentridge, & Neave, 1993; Coren & Halpern, 1991). Porac and Coren (1981) noted a decrease in the left-handed population with age (~15% during adolescence and younger adulthood, 5% during middle adulthood, and 0% after 80 years of age).

As a population, left-handers were 89% more likely to have unintentional injuries requiring medical attention, when compared to right-handers (Coren, 1989). Left-handed individuals tended to report previous unintentional injuries for which they sought physician assistance (Chavance et al., 1990; Graham, Glenn, Dick, Allen, & Pasley, 1992). Several reports have suggested that left-handers sustain unintentional injuries requiring medical attention more often than non-left-handers, and left-handers were five times more likely, as compared to right-handers, to die due to such injuries. With a sample of adolescent athletes Graham, Cleveland, and Bonner (1992) reported that left-handed athletes were more likely than their dexterous counterparts to have previously sought out medical care for an accidental injury. Furthermore, these left-handers had a higher rate of hospitalization for such injuries and as a result, required surgery.

Left-handedness appears to pose a risk for injury even during childhood. An examination of 265 children between 6 and 18 years of age admitted to pediatric emergency care indicated that left-handers comprised 18% of the accidental trauma group. In comparison, a non-trauma control group was comprised of only 10.5% of left-handed children (Graham, Dick, Reckert, & Glenn, 1993). Further support was found in a study which reported that adolescent girls, but not adolescent boys, were 32% more likely to be involved in accidental injuries. Moreover, left-handed children were more likely to incur more severe unintentional injuries and require overnight hospital stays (Wright, Williams, Currie, & Beattie, 1996).

Likewise, Graham et al. (1992) reported that left-handers have a marked risk for unintentional injury. Using a case control method analysis, 761 patients (6-18 years) were surveyed upon their arrival at a hospital emergency room. The patients were divided into two groups - those seeking care for accident-induced trauma and those citing other reasons for admittance. Patients in the accidental trauma group were 67% more likely to be left-handed than those in the non-trauma group. Upon further investigation of retrospective reports obtained from patients' parents, Graham et al. (1992) discovered that being previously hospitalized for injuries related to accidents was 80% more likely if those patients were left-handed. In a population of military personnel, Coren and Previce (1996) showed that knee, elbow, and shoulder injuries were reported more in the left-handed group than in the right-handed group. They also found that in an urban sample of 1,716 individuals, bone fractures were more often reported in non-right-handers. Research by Taras, Behrman, and Degnan (1995) discovered that injuries severe enough to require amputation of one's dominant hand were five times more likely for left-handers than for right-handers. These accounts have been supported by numerous other investigators (e.g., Aggleton, Bland, Kentridge, & Neave, 1994).

Daniel, Yeo, and Gangestad (1992) showed that left-handers' unusually high likelihood for injury continues into adulthood. Based on a sample of 1,469 college students, researchers examined the frequency of accident-induced head trauma with sufficient severity to result in loss of consciousness. These head injuries occurred primarily in situations involving falls, traffic collisions, and contact sports. Upon analysis, it was left-handed college students, both male and female, who were most likely to sustain head injuries resulting in loss of consciousness.

Several researchers have refuted the claim of left-handers' increased likelihood of injury, asserting that it is actually mixed-handers who are at greatest risk for unintentional injury (Daniel & Yeo, 1991; Mandal, Suar, and Bhattacharya, 2001; Segalowitz & Brown, 1991). Upon re-analysis of Coren's (1989) data, Daniel and Yeo (1991) found mixed-handers to be at greater risk for injury than either right- or left-handers. Segalowitz and Brown (1991) found that mixed-handed children had increased rates of mild head injuries than did those with consistent handedness. When looking at accidental injuries sustained while working and driving, Pekkarinen, Salminen, and Jarvelin (2003) reported that males with mixed-handed had a slightly higher risk of home and traffic-related injury. Additionally, ambidextrous females had a moderately increased risk of accidentally injuring themselves at work. Some findings have suggested that both left- and mixed-handers have an equally increased susceptibility to head injury (Daniel and Yeo, 1992).

The risk of injury for mixed-handers is not confined to Western countries as shown in a study from Ida, Dutta, and Mandal (2001) on accidents among people living in Japan and India.

In Japan, ambidextrous individuals had more accidents than consistently left- or right-handers. However, the same study went on to reveal that left-handers from India committed more accidents than did right- and mixed-handers. Another report by Mandal et al. (2001) found that in a sample of 150 male graduate students, accidents were reported more often among ambidextrous men than those with a consistent hand preference. While it is possible that mixed-handedness poses an increased risk for accidents and related injuries, the evidence in support of this hypothesis is inconclusive.

Left-handers may be subject to an increased likelihood of accidents and injuries when engaged in transportation-related activities (e.g., driving/operating a motor vehicle, train, airplane, etc.) In an analysis of airplane pilots, Crowley (1989) found left-handed individuals to pose a greater risk for accidents relative to right-handers. This is supportive of Gerhardt's findings (1959) which reported that left-handed pilots had more difficulty in learning to fly non-civilian aircraft than did pilots who were right-handed. Gedye (1964) presented findings showing that as flying skill increased, the proportion of left- and mixed-handed pilots decreased. Further, two sets of researchers categorized pilots on the basis of flight performance and skill. One group of pilots reported no history of complications or accidents, and the other group had a flight history of reported errors, difficulties, and near misses. The error-prone groups contained a significantly larger number of left- and mixed-handed pilots than right-handers, while the error-free group consisted of predominantly right-handers (Bodrov & Fedoruk, 1985; Gyurdzhian & Fedoruk, 1980).

Analysis of locomotive drivers found similar associations between left-handedness and accident proneness. Using a sample of 80 locomotive drivers (i.e., those that drive and operate the trains), Bhushan and Khan (2006) examined the relationship between accident proneness and hand laterality. Analysis of data revealed that left-handed drivers had a higher accident rate than right-handed locomotive drivers in India. Degree of handedness (i.e., strongly left, weakly left, strongly right, weakly right) did not affect the accident rate than right-handed drivers. Both the weakly and strongly left-handed conductors were more likely to report a higher accident rate than drivers with weak or strong right-handedness. Researchers postulated that the risk for accidents by left-handers may be a result of the locomotives' cabin design which apparently favors right-handers. Locomotives are not intended to turn in a specific direction (i.e., left or right), yet the design of the locomotive cabs was complex and catered strongly to individuals with a right-handed preference. This design, along with the pre-existing complex work demands, may make it more difficult for left-handers to effectively and safely operate locomotives.

Startle Response Reflexes

A reflex response occurs during the presence of an unexpected or startling event, such as a ball flying at one's head, a loud nose, or a sudden movement of objects or persons in the immediate surroundings. During these situations, people tend to show an automatic, unlearned reflexive pattern of behavior. This behavioral pattern shown under circumstances of unanticipated events is known as the startle response (Coren, 1992a). As part of this startle response, people often gasp for breath, begin to perspire, and of particular interest to the present study, they tend to position their hands somewhat out to the front and sides of their bodies. This reflexive behavioral pattern may have evolved as a series of movements to protect the person from frontal attack.

Coren (1992b) discovered that the typical startle reflex response for right-handers is to place their hands directly in front of their body, with the left hand positioned somewhat higher than the right hand. Conversely, left-handers responded to an unanticipated event by positioning the right hand higher than the left hand. These differential behavioral patterns may significantly influence driving behavior. If a driver were to be startled by an unexpected event (e.g., a child runs in front of the car), his or her response might influence the direction of the vehicle's forward motion. Looking at the typical response pattern of a right-hander with the left hand being held high and the right hand low, the driver would rotate the steering wheel in a clockwise direction. This would maneuver the car to the right, onto the shoulder of the road and away from on-coming traffic. On the other hand, Coren (1992b) found left-handers to be more than three times more likely to have a startle response with their right hand high and their left hand low. The result is the steering wheel turns counterclockwise swinging the car out to the left. In situations where driving patterns require right-sided driving, this direction pushes the car into oncoming traffic. Due to this response, left-handers have an increased likelihood of head-on motor vehicle accidents.

Coren (1992b) argued that driving on the right side of the road may pose a risk factor for left-handers in the event that a startle response reflex is elicited. This in turn would increase left-handers' likelihood of head-on vehicle collisions during a startling event. However, if one lived in a country such as England where vehicles are driven on the left side of the road, it would be right-handers who would be more likely to be involved in head-on vehicular accidents. Coren (1992b) tested this hypothesis using data provided by the European Conference of Ministers of Transport. With this, he analyzed the number of traffic accidents per kilometers traveled. Over the 11-year duration of the surveyed period, the combined frequency of vehicular accidents (including head-on collisions, side collisions, hitting the median, etc.) for Britain and Ireland (who use left-sided driving) was higher than the combined accident for 14 other European nations (who use right-sided driving).

Similar observations have been made in Australia, where people also drive their vehicles on the left side of the road in addition to using right-side drive cars. A recent survey by the Australian car insurance company, *First Alternative*, was published in an Australian newspaper article (Daily Telegraph, 2004). Based on survey data, *First Alternative* revealed that left-handed drivers in Australia are safer drivers than right-handers. Australian driving laws are similar to those in Britain and Ireland in that vehicles stay on the left side of the road. Also, the driver's seat is positioned on the right side of the car, so all gear shifting is done with the left hand. The data from this survey continues to point out the advantage for left-handers in countries such as Australia, stating that right-handed drivers, 25 years of age and under, are nearly twice more likely to cause head-on collisions than left-handers from the same group. Also, male drivers who were right-handed were 17% more likely to be at fault for vehicle collisions as a result of turning into lanes with oncoming traffic (Daily Telegraph, 2004).

Due to the the social reluctance to convert children from left-handedness to right-handedness (namely using handwriting skills), as was common practice in the past, a higher frequency of left-handers has been reported in younger populations (Coren & Halpren, 1991; Gilbert & Wysocki, 1992; McManus, Moore, Freegard, & Rawles, 2010)). For the reasons that left-handedness has been cited as a risk factor for unintentional injury in relation to automobiles, and these injuries are a major risk factor for younger age groups, we felt it worthwhile to examine the relationship of the startle response reflex while driving among individuals who demonstrate right-, left-, or mixed-hand dominance. Our particular concern was in regards to head-on collisions and its association with left-handedness. On the basis of the foregoing literature review, three hypotheses will be investigated.

Hypotheses

Hypothesis 1: In reaction to an unanticipated event, left-handed drivers operating a standard American sedan will be significantly more likely compared to right-handers to exhibit a startle response that will steer the vehicle to the left. Previous research by Coren and Halpern (1990) indicated that, following an unexpected event, 76% of left-handers exhibit a startle response with the right hand held higher than the left hand. One purpose of the present study is to examine whether this finding can be replicated during a driving event. If results of the study support this hypothesis, it may provide insight into why left-handers have an increased likelihood of traffic-related injuries. It may also allow a further understanding of the causes, at least in part, of head-on vehicular accidents.

Hypothesis 2: In reaction to an unanticipated event, right-handed drivers operating a standard American sedan will be significantly more likely compared to left-handers to exhibit a startle response that will steer the vehicle to the right. Just as left-handers are likely to display a typical response pattern, right-handers are equally as likely to respond in a similar yet opposite way. As a reaction to a startling event, 79% of right-handers place their left hand somewhat higher than their right hand (Coren & Halpern, 1990). During a driving event where a participant's hands are placed on the wheel, the startle pattern would rotate the steering wheel in a clockwise direction. Coren (1992b) suggested this as an explanation of the differential likelihood of a traffic accident between left- and right-handers. The second purpose is to examine the validity of this previously stated hypothesis.

Hypothesis 3: In reaction to an unanticipated event, mixed-handed drivers operating a standard American sedan will likely not exhibit a startle response that will steer the vehicle to either the left or the right. The final purpose of this study is to determine the direction and degree of turn for drivers who are identified as mixed-handed. Because mixed-handers do not typically display a preferred or dominant hand, and are equally adept with both the left and right hand, findings should indicate no directional preference for a right- or left-handed turn as a function of a startle response.

CHAPTER 3
METHODOLOGY

Participants

Thirty students (11 males, 19 females) attending the University of Central Missouri (UCM) served as participants. Means for age and education were 22.27 years (*SD* = 6.74) and 13.97 years (*SD* = 2.09), respectively. There were 26 Caucasians, 1 African-American, 1 Asian American, and 2 from other ethnicities. There were 14 right-handers (46.7%), 11 left-handers (36.7%), and 5 mixed-handers (16.7%). These classifications were based on actual performance on seven lateral dominance tasks (e.g., throwing a ball, name writing, etc.). All participants were at least 18 years of age, currently enrolled as full-time students (twelve credit hours or more per semester), physically able and willing to operate a motor vehicle, and possessed both a valid driver's license and motor vehicle insurance.

Materials

Handedness Measures. The Edinburgh Handedness Inventory (EHI; Oldfield, 1971) and the Reitan Lateral Dominance Examination (LDE; Reitan & Wolfson, 1993) were employed to assess hand dominance. Participants were classified as predominantly right-handed, predominantly left-handed, or mixed-handed.

The EHI (see Appendix C) is a self-report hand preference questionnaire using 10 items: writing, drawing, throwing, use of scissors, toothbrush, knife (without fork), spoon, broom (upper hand), striking a match, and opening a box (lid). Participants simply indicate their hand preference for each item in the following range: *Always left*, *usually left*, *no preference*, *usually right*, to *always right*. Responses were coded on a 5-point Likert-type scale ranging from -2 to +2. Item scores were then totaled and divided by 5 (e.g., the number of handedness categories listed on the questionnaire), providing the final EHI score. Strong left-handedness received a score of -2, strong right-handedness was identified by a score of +2, and mixed-handedness was assigned to participants with scores in the range of -.5 to +.5.

The LDE (Reitan & Wolfson, 1993) was developed to measure hand and foot performance by having participants carry out actual tasks, and consists of nine items (see Appendix D). Seven measure hand usage to throw a ball, hammer a nail, cut with a knife, turn a doorknob, use scissors, erase a blackboard, and name writing as well as two foot measures that require the participant to step on a bug and kick a ball. The two measures of footedness were not pertinent to the current investigation, and thus were omitted from the examination.

The LDE items for hand writing are phrased “Now I want you to write your full name on the paper” and the examiner instructs participants to use their chosen hand for writing. The examiner then continues with instructions stating “Now I want you to write your name in the same way, using your other hand.” The examiner is to record the dominant and non-dominant hand that is used as well as the duration of time for each name writing trial, but give no further instruction to the participant such to write quickly and/or alter his or her writing manner in any way. The difference between the two name writing times provides further indication for hand laterality. The remaining tasks require the participant to perform a number of one-handed tasks. The examiner is prohibited from pressuring the participant to use one hand or the other. Further, the examiner must present the task materials individually and so they are available for the participant to access easily with either hand. Unlike the writing task of the LDE, these remaining items were specifically chosen because of their lack of heavy influence from social pressures. Before beginning this portion of the examination, it is important that the following items are present in the LDE kit: a small ball, a toy hammer, a plastic toy knife, a pair of scissors, and a sharpened pencil with an eraser. For the first task, the examiner places the ball on a table situated directly in front of the participant and says “Show me how you would throw a ball.” Essentially the same instructions, “Show me how you would…,” are used for the remaining tasks, with the examiner ensuring that the previous item is removed from the participant’s field of view prior to presenting the new iterm for the next task. Participants were asked to inform researchers if they did not have a specific hand preference for a certain task, and researchers recorded that information on the scoring sheet. Points for using the left or right hand for each task are then assigned accordingly. Each item is assigned one point to either the right or left hand, except for the preferred hand for name writing which is assigned 3 points. If participants indicated no hand preference for a task, .5 points were given to each hand. Points for tasks using the right hand and the left hand were totaled, giving a final ratio score. Composite LDE ratio scores of 9:0, 8:1, and 7:2 indicated right-handedness; ratios of 0:9, 1:8, and 2:7 denoted left-handedness; and any ratios of 3:6, 4:5, 5:4, or 6:3 were indicative of mixed-handedness (Russell, Neuringer, & Goldstein, 1970).

The two handedness measures were analyzed in order to provide information regarding their consistency in classifying participants into different handedness groups. Although both the EHI and LDE were used in order to identify hand dominance, the LDE was used as the primary source for handedness identification. Since previous literature has suggested that the strongest predictive model of handedness lies within performance tests, we relied on the LDE as our primary tool for handedness classification. Because of the proposed discrepancies between preference and performance measures of handedness, we felt it worthwhile to further examine the relationship between the two handedness measures.

Procedure

The present investigation was conducted in two parts. Human Subjects approval was obtained concurrently for both Part One and Part Two of the study.

Part One-Demographics Questionnaire and Handedness Measures. After approval was granted from Human Subjects Protection Committee, students taking psychology courses at UCM were asked to take part in the study. With permission from course instructors, the principle investigator (Jennifer Seeley) met with classes at their regularly scheduled times, presented a brief overview of the investigation, and solicited interested participants, especially those who identified themselves as being left-hand dominant. Students that agreed to participate were scheduled to meet with the principal investigator at a later date. At this later meeting, volunteers were asked to sign an informed consent (see Appendix A) prior to participation. In addition, participants were asked to provide personal contact information (i.e., name and e-mail address) so that they could be contacted for Part Two of the study (i.e., the driving component). This portion of the study required approximately 15 to 20 minutes and included a demographic questionnaire (see Appendix B), the EHI (Oldfield, 1971; see Appendix C) and the LDE (Reitan & Wolfson, 1995; see Appendix D).

Part Two-Driving Component. Participants were tested on a driving course at the UCM Traffic Safety Center. Participants, along with a driving instructor, drove a 2000 Chevrolet Malibu provided by the safety center. Upon arriving at the center and prior to taking part in the driving component of the study, participants were introduced to the driving task and given basic instructions from a state-certified driving instructor. Instructions included use of a seat belt while operating the vehicle, placing hands at “9 and 3” on the steering wheel while driving, and not exceeding a speed limit of 30 miles per hour (MPH). The participants then entered a 2000 Malibu along with the driving instructor and were allowed a few minutes to familiarize themselves with the vehicle. The vehicle was equipped with passenger-side breaks to permit the driving instructor to stop the car in the event that the participant was unable or unwilling to operate it as directed.

Once the participant reported feeling comfortable with the vehicle, he or she commenced driving around the course three times. During each trial, participants were directed to drive through an obstacle course which required them to maneuver around a series of rubber cones placed on the road in a prescribed pattern. This was the same obstacle course used by the Safety Center for routine driving assessments and Missouri Police Academy driving training. A graduate student observed the participant from an observation point (see Appendix E) directly east of traffic lights suspended over the expressway section on the driving course. Following completion of the third trial and as the participant was driving the vehicle to the designated parking area; he or she passed a set of three suspended traffic lights. Behind the center traffic light was a box with a trap door, constructed and supplied by the Safety Center, which was filled with 8-9 tennis balls. A steel cable running from the traffic lights to the observation point controlled the trap door. As the participant approached the traffic lights and execution point, the graduate student pulled the cable. This opened the trap door of the box and the tennis balls dropped from above the driving course directly in front of the moving vehicle. These objects were expected to startle the driver, thus causing him or her to apply the brakes and either hit the balls or turn the wheel to avoid contact with the objects. The participants' responses to the objects constituted the dependent variable of interest, and were recorded by the driving instructor using an observation checklist (see Appendix F) which described the position of the steering wheel after the unexpected event.

In addition to the observation checklist scored by the driving instructor, a vehicle surveillance camera was installed in the car in order to capture the movement of the wheel during each participant's driving experience. The ceiling-mounted camera was installed in between the driver and passenger seats, immediately behind the rear-view mirror and aimed directly at the steering wheel. The device, equipped with only video and not audio recording, was placed in such a manner as to focus only on the steering wheel, and not on other elements in the car (e.g., participant and instructor in the vehicle, auditory stimuli, interior design of the car, etc.). Other than the participants' hands on the wheel, no identifying information of either the driver or driving instructor was accessible from recorded footage. Following collection, a professor in the Department of Kinesiology at UCM then analyzed the video footage using Dartfish ProSuite 5.5.20909.0 software file for editing (Swiss Federal Institute of Technology; Lausanne, Switzerland, 2009). Dartfish ProSuite allows researchers to break down individual movements and trajectories within a specific activity, and was employed in this study to determine if any significant startle responses were elicited following the introduction of the tennis balls in front of the vehicle. It was hypothesized that significant startle responses may have been elicited by participants, but due to vehicle manufacturing (e.g., various steering sensitivity based on model, type, and year of car), may have not caused the vehicle to steer in a specific direction.

For the video footage analysis, the steering wheel was bisected as it was most perpendicular to the video camera's point of view. This measurement created a vertical angular reference of .385 millimeters. The parallax error for this measurement was .26. Parallax error is an instrument reading error because the instrument, or in this case the video camera, was not precisely in line perpendicularly to the plane of the scale. A radius was then drawn to the left side of the steering wheel at 90 degrees perpendicular to the vertical line. This created a 10.5 - 11.5 centimeter length. With both lines set at 90 degrees, we were able to derive a center point of reference. These angles assisted in determining the angular velocities used for corrective driving purposes. For the analysis, the drivers' knuckles on the steering wheel were used to measure direction and degree of turning response. The difference between the center point of reference and the varying degree created by the movement of the hand as a result of steering created an angular displacement measurement. As set up, if the angle increased, the steering wheel rotated in a clockwise (right-turn) direction and if the angle decreased the steering wheel rotated in a counterclockwise (left-turn) direction. If the angular degree did not change, the steering wheel did not rotate and the driver did not react to the startling stimulus by steering the vehicle in a specific direction. The degree created by the movement of the driver steering the wheel was examined at specific points during the unexpected driving event. Three angles were analyzed specifically: 1) the starting angle immediately prior to the presentation of tennis balls, 2) the angle during the presentation of the tennis balls, and 3) the angle upon which the driver returned to normalcy in terms of driving in a straightforward direction. At times, there was a fourth angle that was measured and in these cases there was an extended period of time between the reaction to the tennis balls and a return to driving normalcy. This video footage was meant to act as supplementary information for the observation checklists, and was also expected to increase the reliability of the data. Following analyses, all video footage was eliminated and destroyed. The participants' responses, as recorded by the observation checklist and the video footage, constituted the dependent variables of interest in this study.

CHAPTER 4
RESULTS

A total of 41 UCM students participated in the first part of the study. Following this portion of the study, participants were asked to provide contact information and then assigned a specific date and time for which they were to take part in the driving component of the study at the UCM safety center. Researchers provided explicit directions to the driving center, and send reminder e-mail notifications to participants one day prior to their scheduled driving appointment. Of the 41 participants, 30 (73.1%) took part in the second portion of the study. The remaining 11 participants who did not complete the driving trial were unable to arrive for their scheduled driving appointment and/or not available for driving at a later, rescheduled date.

Comparison of the Two Handedness Measures

Detailed analyses of the concordance between the Edinburgh Handedness Inventory (EHI) and Reitan Lateral Dominance Examination (LDE) were conducted in order to assess the classification agreement between the two types of handedness measures. Table 1 displays the hand dominance classifications according to both measures. The direction of handedness (e.g., right-, left-, or mixed-handed) as determined by the EHI and LDE was first examined. Based on the scores, 28 (93.3%) of the participants were classified similarly on both the EHI and the LDE. Only two participants (6.7%) received contradictory handedness classification scores from the self-report test and the performance test. This disagreement occurred exclusively for participants with left- or mixed-handedness. Second, the strength of the participants' handedness (i.e., strongly left-handed, weakly left-handed, mixed-handed, etc.) was compared. This analysis showed less consistency between the EHI and LDE, with only 24 participants (80%) receiving identical classifications on both tests. Six participants (20%) were assigned different strengths of handedness according to scores from the two tests. Disagreement occurred for right-, left-, and mixed-handedness. Results indicated that the classification consistency between the hand preference measure (EHI) and the hand performance measure (LDE) were substantial for the identification of the direction of handedness, but lacked congruity in the determination of handedness strength. Being as the LDE is a hand performance measure, and its items are objective and reliable, we used it as the primary tool to identify the handedness of participants in the present study (Porac, Friesen, Barnes, & Gruppuso, 1998).

Table 1
Frequency of Participants' Direction of Handedness and Strength of Handedness According to the Edinburgh Handedness Inventory (EHI) and Reitan Lateral Dominance Examination (LDE)

Handedness Variables	Handedness Measure	
	EHI *n* (%)	LDE *n* (%)
Direction of Handedness		
Right-Handed	14 (46.7%)	14 (46.7%)
Left-Handed	13 (43.3%)	11 (36.7%)
Mixed-Handed	3 (10.0%)	5 (16.7%)
Strength of Handedness		
Strongly Right-Handed	10 (33.3%)	13 (43.3%)
Weakly Right-Handed	4 (13.3%)	1 (3.3%)
Mixed-Handed	3 (10.0%)	5 (16.7%)
Strongly Left-Handed	7 (23.3%)	6 (20.0%)
Weakly-Left Handed	6 (20.0%)	5 (16.7%)

Observational Driving Checklist

The reaction of drivers following the unanticipated event, the dropping of the tennis balls, was analyzed according to the observational driving checklist. The frequency and percentage of drivers' directional turning responses (no turn, right turn, or left turn) as a result of the unexpected event are presented in Table 2. As shown in Appendix F, steering responses were based on the degree to which the steering wheel was rotated in reaction to the unexpected stimulus. According to the checklist, 15 (50%) drivers did not exhibit a turning response and 15 (50%) drivers exhibited a response by steering either to the right or to the left. There were no differences among the three handedness groups (right, left, or mixed) in regards to their probability to turn or not turn in response to the unexpected event, χ^2 (2, 30) = 1.30, *p* = .52. To further assess the response, a proportional analysis was run in order to determine if there was any underlying significance with the reactions observed using the observation checklist. First, mixed-handed drivers were compared to both right- and left-handed drivers combined in order to determine if their turning reactions to the surprise stimulus differed based on handedness. The proportional analysis indicated that turning responses of mixed-handers was not significantly different from either right- or left-handers (z = -.94, p = .83). Second, left-handers and right-handers were compared based on their turning reactions as recorded by the observation checklist. Consistent with Coren's (1992b) suggestion of an association between handedness and direction of turn as a function of a startle response reflex (e.g., Coren, 1992b), right-handed drivers were more likely than left-handed drivers to steer the vehicle to the right following the presentation of the unexpected stimulus (z = 3.75, $p < .001$). Also, the proportion of left-handed drivers that turned to the left was significantly higher than the proportion of right-handers with the same left-sided turn response (z = -5.24, $p < .001$).

Table 2
Frequency and Percentage of Participants' Direction of Turn According to the Observational Driving Checklist

Handedness of Drivers	Turning Direction		
	No Turn *n* (%)	Right Turn *n* (%)	Left Turn *n* (%)
Total (N = 30)	15 (50.0%)	7 (23.3%)	8 (26.7%)
Right-Handers (n = 14)	8 (57.1%)	5 (35.7%)	1 (7.10%)
Left-Handers (n = 11)	4 (36.4%)	0 (0.0%)	7 (63.6%)
Mixed-Handers (n = 5)	3 (60.0%)	2 (40.0%)	0 (0.0%)

Additional analyses using the observational checklist were conducted in regards to the degree of turn elicited following the presented stimuli. Table 3 presents the frequencies and percentages of drivers' degree of turn. As stated previously, turning responses were measured according to the degree to which drivers rotated the steering wheel in a specific direction. Because of this, a turning was response which rotated the steering wheel ≤ 24 degrees was categorized as a slight turn and not sufficient enough to significantly turn the vehicle in a specific direction while moving at a speed of approximately 30 MPH. A steering wheel rotation of ≥ 25 degrees was however sufficient to turn the vehicle in a specific direction and was classified as a quarter turn. Findings from the observational checklist revealed that no left-handed drivers steered to the right. Interestingly however, one right-handed driver did exhibit a left-hand turning response.

Table 3

Frequency and Percentage of Participants' Degree of Turn According to the Observational Driving Checklist

Handedness Group	Degree of Turn *n* (%)				
	No Turn	Quarter [a] R	Slight [b] R	Quarter [a] L	Slight [b] L
Total ($N = 30$)	15 (50%)	1 (3.30%)	6 (20%)	3 (10%)	5 (16.7%)
Right-Handers ($n = 14$)	8 (57.1%)	1 (7.10%)	4 (28.6%)	1 (7.10%)	0 (0.0%)
Left-Handers ($n = 11$)	4 (36.4%)	0 (0.0%)	0 (0.0%)	2 (18.2%)	5 (45.5%)
Mixed-Handers ($n = 5$)	3 (60%)	0 (0.0%)	2 (40%)	0 (0.0%)	0 (0.0%)

[a] Quarter Turn = Steering wheel rotated approximately 25 degrees and was sufficient enough to turn the vehicle in a particular direction (e.g. right or left turn) while moving at a speed of ~ 30 MPH
[b] Slight Turn = Steering wheel rotated <25 degrees which was not sufficient enough to turn the vehicle in a particular direction while moving at a speed of ~30 MPH

In addition to the observational checklist, drivers' steering responses were also analyzed using video footage software. Footage was recorded using a Nikon Coolpix s3000 digital camera. The video footage for each participant was approximately 4 minutes in length and was stored on a Dell Optiplex 745 Desktop computer and then transferred to a Dartfish ProSuite 5.5.20909.0 software file for editing (Swiss Federal Institute of Technology; Lausanne, Switzerland, 2009).

Table 4 presents drivers' handedness and turning reactions based on results from the Dartfish digital analysis software. Right-, left-, and mixed-handed drivers did not differ in terms of their likelihood to turn or not turn in reaction to the surprise stimulus. However, there was an association between type of handedness and likelihood to turn to the left or right following the presentation of the tennis balls. According to the analysis, drivers who were right-handed were more likely to have steered right in reaction to the surprise stimulus than drivers who were left- or mixed-handed, χ^2 (2, 30) = 6.06, $p < .05$. This seems to represent the fact that the odds of a startle response reflex eliciting a right hand turning response was 10.60 times higher if the driver was right-handed rather than left- or mixed-handed.

Table 4

Frequency and Percentage of Participants' Direction of Turn According to the Dartfish Prosuite Software

Handedness of Drivers	Turning Direction		
	No Turn *n* (%)	Right Turn *n* (%)	Left Turn *n* (%)
Total (N = 30)	9 (30%)	10 (33%)	11 (36.7%)
Right-Handers (n = 14)	5 (35.7%)	7 (50%)	2 (14.3%)
Left-Handers (n = 11)	3 (21.3%)	0 (0.0%)	8 (72.7%)
Mixed-Handers (n = 5)	1 (20%)	3 (60%)	1 (20%)

Hypothesis 1: In reaction to an unanticipated event, left-handed drivers operating a standard American sedan will be significantly more likely compared to right-handers to exhibit a startle response that will steer the vehicle to the left.

As displayed in Table 2, left-handed drivers were significantly more likely to steer the vehicle to the left as a function of a startle response reflex. Drivers who were left-handed were also more likely to display a more drastic left side turning response. Eighteen percent of left-handed drivers displayed a left side turn that was drastic enough to steer the vehicle to the left while moving at a relative speed of 30 MPH. Proportional analyses indicated a significant difference between the proportions of left-handed drivers and right-handed that turned to the left as a response to the stimuli. The findings from Dartfish ProSuite digital analysis software supported these findings and are presented in Table 4. According to both the observation checklist and digital software, no left-handed drivers reacted to the stimulus by steering the vehicle in a rightward direction.

Hypothesis 2: In reaction to an unanticipated event, right-handed drivers operating a standard American sedan will be significantly more likely compared to left-handers to exhibit a startle response that will steer the vehicle to the right.

Table 2 shows that, according to both the observation checklist, right-handed drivers displayed a significantly higher rate of right-handed turns than did left-handed drivers. According to the observation checklist, only 1 right-handed driver responded to the startling stimulus by steering the vehicle to the left. As shown in Table 4, digital analysis confirmed the hypothesis with findings showing an increased likelihood of right-handers to display a right side turn. However, the digital software did indicate that two of the right-handed drivers reacted to the tennis balls by steering in the leftward direction.

Hypothesis 3: In reaction to an unanticipated event, mixed-handed drivers operating a standard American sedan will likely not exhibit a startle response that will steer the vehicle to either the left or the right.

As shown in Table 2, the frequency of directional turns as recorded on the observational checklist did differ among participants in the mixed-handed group. The majority of mixed-handed drivers did not steer the vehicle following the presentation of the startling stimulus, and did not display a significant startle reaction. For those mixed-handers that did react to the stimulus, the observation checklist findings reported that two displayed a slight turn in the rightward direction. Conversely, the digital software findings indicated that one mixed-hander driver steered to the right and one driver to the left in response to the unanticipated event. Mixed-handed drivers more commonly did not react to the unexpected variable by turning the vehicle, and the proportion of these drivers that did steer the vehicle in a particular direction was equal for both left- and right-sided turns (according to the Dartfish ProSuite findings).

CHAPTER 5
DISCUSSION

The current investigation posed three major hypotheses: (a) left-handed drivers should display a significant startle response reflex that results in a left-sided turning preference, (b) right-handed drivers should exhibit a significant startle response reflex that results in a right-sided turning preference, and (c) mixed-handed drivers will not display a significant preference for a right- or left-sided turn. The data from the observational data and digital analysis software indicated that handedness did play a significant role in predicting the turning direction following the presentation of the startling stimulus. Additionally, it was found that left-handed drivers were more likely to exhibit a left side turn and right-handers were more likely to display a right side turn. Mixed-handers did not display a significant trend to turn in either direction, and often did not steer the vehicle in reaction to the tennis balls. These patterns are similar to those postulated by Coren and Halpern (1990), and also consistent with previous studies examining startle responses elicited during non-driving events in which individuals displayed their hands in a pattern indicative of their handedness (Coren, 1992b). The present study provides compelling evidence for a difference in the turning reactions following unanticipated driving events as a result of different components of hand laterality.

Handedness

The present study employed two measures of handedness – a hand preference questionnaire and a hand performance examination. Previous research has generally classified handedness based on self-reports of handedness or classifications based on hand preference questionnaires (e.g., Annett, 1970; Coren, 1989; Graham et al., 1992; Bhushan & Khan, 2006; Raymond & Pontier, 2004; etc.). This made it difficult to compare our findings to many of the previous studies on handedness. Hand preference tests and self-reports are popular research tools due to their ease of group administration and scoring. Unfortunately, these measures are often criticized in terms of their validity because of the subjective responses used to assess handedness (Bryden et al., 2000). Hand performance tests, such as the Reitan Lateral Dominance Examination (LDE; Reitan & Wolfson, 1993), eliminate this concern by observing individuals as they actually execute uni-manual tasks. These observational methods reduce subjectivity and provide researchers with concrete evidence for handedness classification. Thus, some researchers consider hand performance assessments to be superior to more subjective measures (Bryden et al., 2000) Other researchers have suggested that the two types of measures be administered separately and then compared in order to derive handedness (Annett, 1970, 1976). A weakness of Annett's suggestion is the fact that few measures of hand preference and hand performance carry with them identical items for which to assess. Thus, many tests cannot be easily compared based on their dissimilar items.

The present study utilized a hand preference measure of handedness, the Edinburgh Handedness Inventory (EHI; Oldfield, 1971) and a hand performance measure, the Reitan Lateral Dominance Examination (LDE; Reitan & Wolfson, 1993). There are currently no other studies that compare the same handedness tests that were used in the present study. Although the EHI and LDE have been incorporated as components of several investigations, they have never been used in conjunction with one another in a single study. In terms of direction of handedness (i.e., right-, left-, mixed-handed), the EHI and LDE generally classified individuals similarly with only two persons receiving different handedness assignments. Classification of degree of handedness however was much more divergent between the EHI and LDE. For this comparison, only 80% of participants were assigned similar designations for their strength of handedness.

Researchers postulated that this discrepancy may be due to the fact that some of the items comprising the LDE, although similar, are not identical to those within the LDE. Thus, it would be understandable that the scores between the two types of assessments may be somewhat different. Based on suggestions from previous research (i.e., Bryden et al., 2000), the LDE was used as the principal handedness classification measure. The utilization of this measure as the primary indicator of handedness was considered a strength of the study. Being that the LDE requires participants to carry out actual tasks provides an objective assessment of handedness. This type of hand performance measure reduces the level of subjectivity that is present in other assessments of handedness such as those seen in self-reports and hand preference questionnaires. In order to eliminate discrepancies such as those found between the EHI and LDE, future research should utilize hand performance and hand preference measures that include identical items on each of the scales. This would allow a direct correlation between the two types of tests and likely reduce mixed classification findings.

Turning Responses

The hypothesis that left-handers would be significantly more likely to turn to the left in response to an unanticipated driving event was confirmed. As stated earlier, this may be due to an automatic unlearned reflex of left-handers, in which they will present their hands in a way as to protect themselves from frontal attack. Also, notice that this reflexive behavior of left-handers places their dominant hand lower than their non-dominant hand; this may be an attempt to protect the preferred hand from injury. Likewise, the second hypothesis that right-handers would turn to the right following unexpected stimuli while driving was supported.

Findings of the present study are skewed due to the proportion of left-, right-, and mixed-handed participants, 43.3%, 46.7%, and 10%, respectively. This was due to the fact that our sample was not random in nature, but rather left-handers were deliberately solicited for participation. These proportions are dissimilar to those found in the general population, specifically within Western countries (Coren & Halpern, 1991). Future research should use equal numbers of left-, right-, and mixed-handed participants in order to allow for more substantial data interpretations.

These findings may provide an explanation for the increased rate of traffic-related accidents in left-handed populations as compared to right-handers (Coren & Halpern, 1991). In many Western countries roadways are designed with vehicles using right-side drive, catering to the predominant group of right-handers. This appears to be related to response patterns during which drivers may become startled by some event (i.e., a child runs out in front of a car). For those that react by turning their vehicle to the right, this would direct the vehicle away from oncoming traffic and likely into a ditch or side of the road. Unfortunately, left-handers are not as likely to display this type of reaction but would have an opposite response of steering the vehicle towards the left. In the United States where vehicles are driven on the right side of the road, this left hand turn would direct the driver's vehicle into oncoming traffic or a road median. This obviously would increase the likelihood of an accident and potentially cause injuries and/or fatalities.

Some limitations regarding the driving component of the study were noted. One of the of these affects the study's generalizability to highway road systems since participants were required to drive at reduced speeds when completing the course. We believe the same turning maneuvers at highway speeds of 70 MPH would be far more severe and drivers would likely swerve the vehicle in a more drastic way. It is important to note that the current study was forced to operate within realistic constraints for safety. Because of this, the study was limited in its abilities to replicate a real-life scenario highway situation. In order to generalize findings to a highway scenario, optimal conditions would involve a straight track similar to a major roadway stretching five miles in length where drivers would have the ability to drive at highway speeds. Being as this type of driving course was not available for use in the current investigation, we attempted to replicate a real driving scenario as closely as possible. Although this is a pilot study, it does provide significant insights into the reactions of left-, right-, and mixed-handed drivers. These insights may assist transportation officials and roadway engineers in decreasing the frequency of annual road traffic accidents in the United States.

Other variables that may have limited the study's findings and generalizability were also identified. We attempted to eliminate as many confounding variables as possible in the following way: drivers drove during ideal weather conditions with no precipitation or harsh winds to affect driving; texting and talking on phones was prohibited while driving the vehicle; no music was allowed to be played during the duration of the driving component; a driving instructor was present in the vehicle for each participant and provided explicit instructions as how to maneuver through the course; no passengers other than the driving instructor and participant were present in the vehicle; no other vehicles were present on the track during the driving trials; the artificial track was clearly marked/defined and fenced in, controlling any pedestrians, animals, and/or unauthorized vehicles from entering the course during the driving trial. It is understood that this controlled environment is not typical of those experienced during real driving situations. In an uncontrolled situation, drivers would likely experience distractions both inside and outside the vehicle. Although participants drove under controlled circumstances, their startle reactions provide insights concerning the likely responses that would occur under normal driving conditions. Perhaps the startle reactions during normal driving would be far stronger because of driving distractions such as traffic on the road, vehicle speed, passengers in the car, music playing, poor weather conditions, etc.

All participants drove a 2000 Chevrolet Malibu on an enclosed track. The vehicle was provided by the Driving Center and was formerly used by highway patrolmen on major roadways. Currently, the vehicle is used for officers' driving training by the Missouri Police Academy. The Malibu was in good working condition with no major technical or exterior problems that may have affected its operation. Due to the fact that the vehicle was older, the steering suspension was possibly not as precise as that typically seen in newer vehicles. The steering insensitivity may have affected the way in which the vehicle rotated as a result of drivers steering the wheel while driving at a relatively low speed. It would have been ideal to have had drivers drive a newer car with a more sensitive steering mechanism. A more precise and responsive steering automobile might have produced more extreme turns in reaction to the startling stimulus which could be easily observed by the driving instructor.

The additional concerns were identified upon analysis of the Dartfish ProSuite software driving video. Explicit instructions regarding hand position on the wheel at a "9 and 3" placement were given to participants prior to driving the vehicle, not all drivers obeyed this instruction. This preliminary measure was taken not only to insure proper control of the vehicle while driving but also to allow for a uniformed focal point that would later assist with video analysis. The Dartfish ProSuite software was used to measure angular displacement based on angles determined by factors such as the diameter of the steering wheel, the position of the drivers' hands on the wheel, and the rotation of the wheel as a result of some turning response. In order to provide the most accurate measures of displacement, it was important to require all drivers position their hands on the wheel in a way as similar to one another as possible.

Unfortunately as mentioned above some drivers did not comply with the specific “9 and 3” directions that they were given, and continued to improperly position their hands on the wheel even after they were advised by the driving instructor monitoring their behavior in the vehicle. Due to this factor, the angular displacement findings from the Dartfish software analysis were gross at best. The focal length as measured by the angles from the hand placement and steering wheel measurements changed throughout the video footage due to the consistent changes in the drivers’ hand position on the wheel. Although the quantification capabilities were not affected, this hindrance did create some difficulties in ascertaining focal points for which to measure angular measurement. Thankfully, the perspective error (.26) was small enough that the angular displacements were able to be generalized. Future research designs should take care in safeguarding against hand displacements while drivers are controlling the steering wheel. This will increase generalizability to more general driving settings, and possibly allow for more significant startle response observations.

Participant Limitations

The sample size of the current study was small which limits the study’s generalizability. While running the Chi – square analysis, multiple cells contained an expected count lesser than the minimum count expected. The small expected count may explain the lack of significant findings in our initial analysis of the observational checklist reactions. Luckily, proportional analyses did indicate significant differences in the turning responses of left-, right-, and mixed-handed drivers. Due to these occurrences, our research findings should be perceived with caution and the findings are not suitable to generalize to the population of all drivers. Our hope is that future research will replicate this study using a larger sample.

All participants were between 18 and 48 years of age, with 90% of the sample between the ages of 18 and 28 years. Only three participants were over the age of 30 years. No drivers under the age of 18 or over the age of 50 participated in the study. The restricted age of the participants may have affected the results. Perhaps the findings would have been different if the investigation utilized an older population of individuals. It would be interesting to examine the role that advancing age plays on driving behavior and, more specifically, startle response reflexes. Recent research has noted the increased proportion of elderly individuals within the population. The number of people ≥ 65 years old increased 10-fold in the past 100 years; this is compared to the less than 3-fold increase of individuals within the same time period who are < 65 years of age (Lutz, Sanderson, Scherbov, 2008). With this increased number of elderly individuals, there is likely to be an increased number of elderly drivers. Unfortunately, these elderly individuals often carry with them longevity-related disadvantages such as declines in sensory capabilities which are needed to successfully perform while driving. Research has recently reported deficits in elderly individuals which may adversely affect driving behavior. Visual impairment and cognitive deficits such as reduced processing speed were more likely to be reported by persons over the age of 50, and people with such handicaps were also likely to report being involved in more traffic accidents (Hickson, Wood, Chaparro, Lacherez, & Marszalek, 2010). With the increasing elderly population, it is expected that a larger proportion of senior drivers will be present on the roadways raising the potentiality for vehicular accidents. Directing this issue more specifically to handedness, elderly left-handers may be at an even greater risk for vehicular accidents and collisions than senior drivers with different handedness classifications. Van de Elst et al. (2008) discovered that not only are elderly left-handers at an increased risk for early onset Alzheimer's disease, they are also more likely to have a rapid cognitive decline following Alzheimer's diagnosis. Perhaps left-handed drivers are at a greater risk for experiencing traffic accidents than drivers with other types of handedness due to their increased susceptibility to dementia-related disorders. We suggest that future studies examine closely age as a variable affecting startle response reflexes while driving. Perhaps the findings for this study would be different if the participant sample included elderly persons.

Future Implications for Research

Previous research has associated left-handedness with an increased risk of accidental injuries while driving. They are 85% more likely than right-handers to sustain injury during a collision or other vehicular accident (Coren, 1989). Other reports claim that the risk for driving injuries in left-handers is almost two times higher than for right-handed drivers (Halpern & Coren, 1991). With this increased risk for injuries, it would be sensible to postulate that left-handers are more often involved in traffic accidents and also that these accidents are severe enough to cause physical injury. Due to the multiple analyses required for the observational data, these possible linkages were not specifically examined. It would be interesting to look at the relationships between vehicle accident history, handedness, and startle response reactions. Perhaps those individuals with left-sided startle response reflexes will also report a higher rate of previous traffic accidents; persons with such a reflex may also describe a history of roadway accidents that were more severe and life-threatening than those reported by drivers with a right-sided reflex response. Therefore, future research should consider obtaining detailed accident histories of all participants through interviews or detailed essays. This information could then be compared to startle response reactions in order to determine if drivers with a left-sided turning reflex do in fact report a larger number of vehicle accidents than those drivers without such a reflexive reaction.

Further research is needed to determine if a more significant turning reaction would be initiated during driving speeds typically seen on interstate highways (i.e., >60 MPH). This could potentially increase the likelihood of turning, in addition to the degree of turn. In conclusion, this preliminary study did provide some insight into the direction of steering for left- and right-handers following an unanticipated driving event. This was the first study to utilize such a method using actual vehicles and driving courses. Although further research is needed to more strongly reflect differences in the way left- and right-handers turn, this study is indicating that there may be a variation in turning responses based on an individual's classification of handedness.

The current pilot study examined handedness as a predictor for startle response reflexes and the ways in which those reflexes affected driving behavior. Although the study has limited generalizability, it does provide some insights for future research. If subsequent, more rigorous studies follow up with the current findings then this may carry implications for automobile insurance companies. Previous research has demonstrated that left-handers are more often involved in traffic accidents, and this relationship may be due, at least in part, to their startle response reflexes originally described by Coren (1992b). If Coren's suggestion is supported by additional studies then insurance companies may feel the need to adjust car insurance rates for left-handed drivers. It would make sense that drivers who are at a greater risk for vehicular accidents pay a higher insurance premium as is already required for certain populations, such as males and persons under 25 years of age. If left-handers are viewed as another group of drivers posing a risk to roadway safety then insurance organizations may feel the need to assure that these drivers obtain increased liability premiums.

Insurance companies would not be the only beneficiaries to this new finding, but motor vehicle agencies may also find this information useful. Motor vehicle agencies manage multiple databases containing demographic information for every person who is issued a driver's license. Databases contain general information including drivers' height, weight, hair color, eye color, driving restrictions (i.e., corrective lenses, hearing devices, mechanical and/or prosthetic aid, etc.), and organ donation. Not only is this information held within a protected database, it is also listed on an individual's license. These facts alert law enforcement individuals about the driver, and may also be useful in situations when medical care is required. To the best of our knowledge, no motor vehicle department requires drivers to provide their handedness as part of the general information they collect. If it is determined that handedness is an important variable driver safety, motor vehicle departments should start including this as required material to be stored within their databases. In the event that a head-on collision occurs on a roadway system, the supplementary handedness information may provide law enforcement additional insights into the cause of the vehicular accident. Handedness would be similar to driver data such as visual acuity and physical handicaps that may predispose individuals to an increased likelihood for collisions.

Driver education courses may wish to develop new training methods as a result of the information from this study. Currently, all drivers are taught identical driving procedures with no specialized instruction based on handedness. Enhanced methods would train left- and right-handed drivers to overcome their natural reflex to turn in the direction of the dominant hand.

Conclusion

In conclusion, the present investigation was a pilot study that raised more questions than it answered. We now know that the hypotheses tested in the study are potentially important for understanding how natural startle responses impact driving stability. The results of the present study did support the hypotheses and left-handedness seemed to be associated with an increased incidence of left-sided startle response reflexes in reaction to startling driving events, and right-handers were more likely to exhibit an opposite, right-sided reflex response. These findings support the initial hypotheses by Coren (1992b) which described a reflexive reaction ingrained in individuals with particular handedness classifications. Due to the preponderance of the body's desire to protect the dominant hand, a specific reflexive behavior is exhibited during situations where the body is facing frontal attack (such as when a muffler detaches from the vehicle driving in front of you and shoots up into your windshield). With the help of more accurate methods of video recording driving behavior, future research may provide further explanations for these observations. This information provides a basis for more sophisticated investigations.

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APPENDIX A
INFORMED CONSENT FORM

Identification of Researcher: This research is being conducted by Jennifer S. Seeley, Department of Psychology, and University of Central Missouri. Assisting me in this project is Dr. Joseph J. Ryan, Department Chair of Psychological Science, and Jim Delap, Program Manager for Transportation Safety at the Missouri Safety Center.

Purpose of the Study: The purpose of this study is to determine whether handedness has an effect on driving behavior while operating a motor vehicle.

Request for Participation: We are inviting you to participate in a study that compares driving behavior performance with motor vehicles among left-, right-, and mixed-handed individuals. Your participation is voluntary. If you decide not to take part, there is no penalty and your status in the Department of Psychology and the University will not be affected. If you choose to participate, you may choose to withdraw at any time without penalty. You may also withdraw your data at any time prior to completion of the study. If you volunteer and are a student in General Psychology (or any other psychology course that accepts research credits) you will receive research participation credit to compensate you for your time and cooperation.

Exclusions: You **MUST** be at least 18 years old to participate in the study and must be enrolled as a full-time student at the University of Central Missouri. You must also have BOTH a valid driver's license and motor vehicle insurance and be physically able and willing to operate a motor vehicle.

Description of Research Method: You will be asked to complete two brief handedness inventories that will objectively determine hand dominance, in addition to completing a demographic survey. Qualified individuals will be introduced to the driving task at the Missouri Safety Center and complete three driving course trials (e.g., drive around an enclosed course with a Safety Center-issued vehicle equipped with passenger side-breaks and a driving instructor). Footage of steering wheel will be recorded during each driving task. Other than the view of your hands on the steering wheel, your identification will not be accessible from the footage. The entire driving session should take about 10 minutes to complete.

Privacy: All research information will be confidential. You will be identified only by a number and no one other than the investigator will have access to your data. All data and related information to the study will be properly locked and stored in the principal investigator's office.

Explanation of Risks: The risks associated with the participation in this study are actually less than those encountered during everyday driving. The driving instructor will be prepared to assume control of the vehicle to ensure safety. If the participant does require medical treatment or emergency service related to this study, any associated costs will be the responsibility of the participant.

Explanation of Benefits: Your participation in this study will help advance our knowledge concerning the use and interpretation of driving behavior among left-, right-, and mixed-handed individuals. This is the first known study to assess the effect of handedness specifically related to driving behavior.

Questions: If you have any questions about this research, please contact Jennifer Seeley. She can be reached at jss64580@ucmo.edu or at (660) 543-4185. If you have any questions about your rights as a research participant, please contact the Human Subjects Protection Program at (660) 543-4621.

If you would like to participate, please sign a copy of this letter and return it to me. The other copy is for you to keep.

I have read this letter and agree to participate.
Signature:___________________________
Date:_______________________________

APPENDIX B
DEMOGRAPHICS INFORMATION SURVEY

Participant # _________ Today's Date __/__/__

1. Age in years:_________
2. Gender (circle one):
   a. Male
   b. Female
3. How many years of education have you completed? For example, if you are a high school graduate you would put 12 years, if you have completed one year of college you would put 13 years, etc._____________
4. Ethnicity/Race (circle one):
   a. White/Caucasian
   b. Black/African American
   c. Hispanic/Latino
   d. Asian American
   e. Other (specify):___________________
5. Are you right- or left-handed?
   a. Right-handed
   b. Left-handed
   c. Ambidextrous
6. Is your mother or father left-handed?
   a. Yes
   b. No
   c. Not sure/Don't know
7. If yes, please indicate which parent is left-handed.
   a. Mother
   b. Father
   c. Both parents
   d. Don't know/Not Applicable
8. Do you have any left-handed siblings?
   a. Yes
   b. No
   c. Not sure/Don't know
9. Occupation:____________________
10. Are you currently taking any medication that could potentially interfere with operating a vehicle (e.g., sleep aids, anti-anxiety medication, etc.)?
    a. Yes
    b. No
11. If yes, please list EACH of them below.

12. Do you have normal hearing and vision (with necessary aid)?
    a. Yes
    b. No
13. Do you currently have a valid driver's license AND motor vehicle insurance?
    a. Yes
    b. No
14. How many years have you been driving motor vehicles?
    a. 1-3
    b. 4-6
    c. 7-9
    d. 10+
15. How many traffic violation tickets have you received?
    a. 0-2
    b. 3-5
    c. 6-8
    d. 9 or more
16. If you have received traffic violation tickets, please list EACH reason for the tickets below.

17. Has your driver's license ever been revoked or taken away?
    a. Yes
    b. No
18. If yes, please explain the reasons why.

19. At this time, are you legally allowed to operate a motor vehicle?
    a. Yes
    b. No
20. Have you ever driven a vehicle and been in a traffic-related accident with yourself and/or another vehicle?
    a. Yes
    b. No
21. If yes, please explain in detail the circumstances of EACH event.

22. Have you ever driven a vehicle and been in a traffic-related accident that did not include another vehicle (e.g., you hit a road median with your vehicle; you rolled your car into a ditch, etc.)?
    a. Yes
    b. No
23. If yes, please explain in detail the circumstances of EACH event.

APPENDIX C
EDINBURGH HANDEDNESS INVENTORY

	Always Left	Usually Left	No preference	Usually Right	Always Right
Writing					
Drawing					
Throwing a ball					
Using scissors					
Using a toothbrush					
Using a knife (without a fork)					
Using a spoon					
Using a broom (upper hand)					
Striking a match					
Opening a box (holding the lid)					

Please mark the box (i.e. use a ✗ or ✓) that best describes which hand you use for the activity in question.

APPENDIX D
REITAN LATERAL DOMINANCE EXAMINATION

Name of Examinee:______________________________ Date:___________

Name of Examiner:______________________________

1. Show me your:
   a. Right hand _____________
   b. Left ear _____________
   c. Right eye _____________

2. Write your full name:
   a. Preferred hand (Right/Left) _______________sec.
   b. Non-preferred hand (Right/Left) _______________sec.

3. Show me how you would:

			Right	Left	
a.	Throw a ball	(1)	_____	_____	(1)
b.	Hammer a nail	(1)	_____	_____	(1)
c.	Cut with a knife	(1)	_____	_____	(1)
d.	Turn a door knob	(1)	_____	_____	(1)
e.	Use scissors	(1)	_____	_____	(1)
f.	Use an eraser	(1)	_____	_____	(1)
g.	Write your name	(3)	_____	_____	(3)

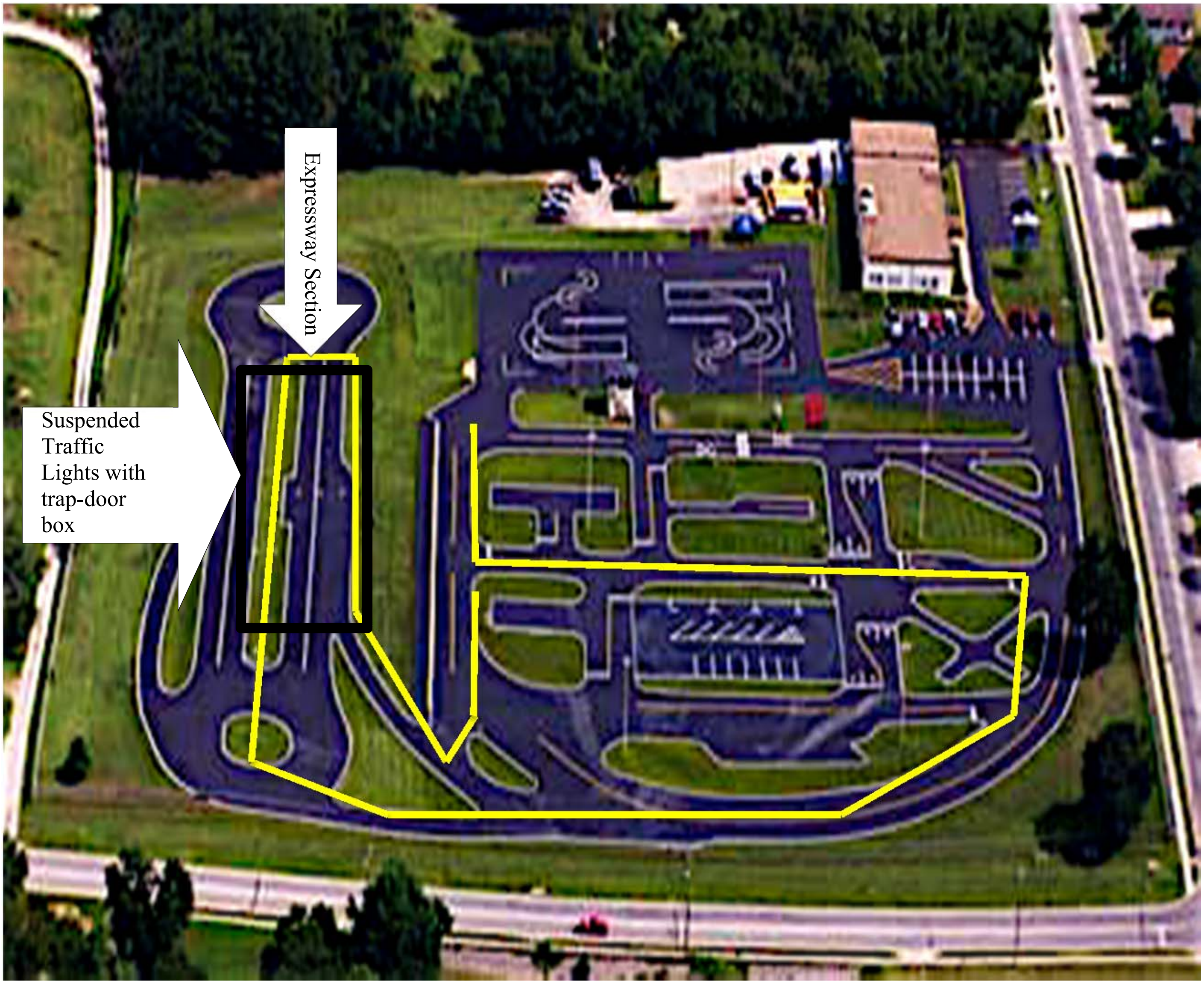
4. Scoring:

   Total points for tasks that used right hand: _______

   Total points for tasks that used left hand: _______

   Dominant hand (circle one): Right hand Left hand

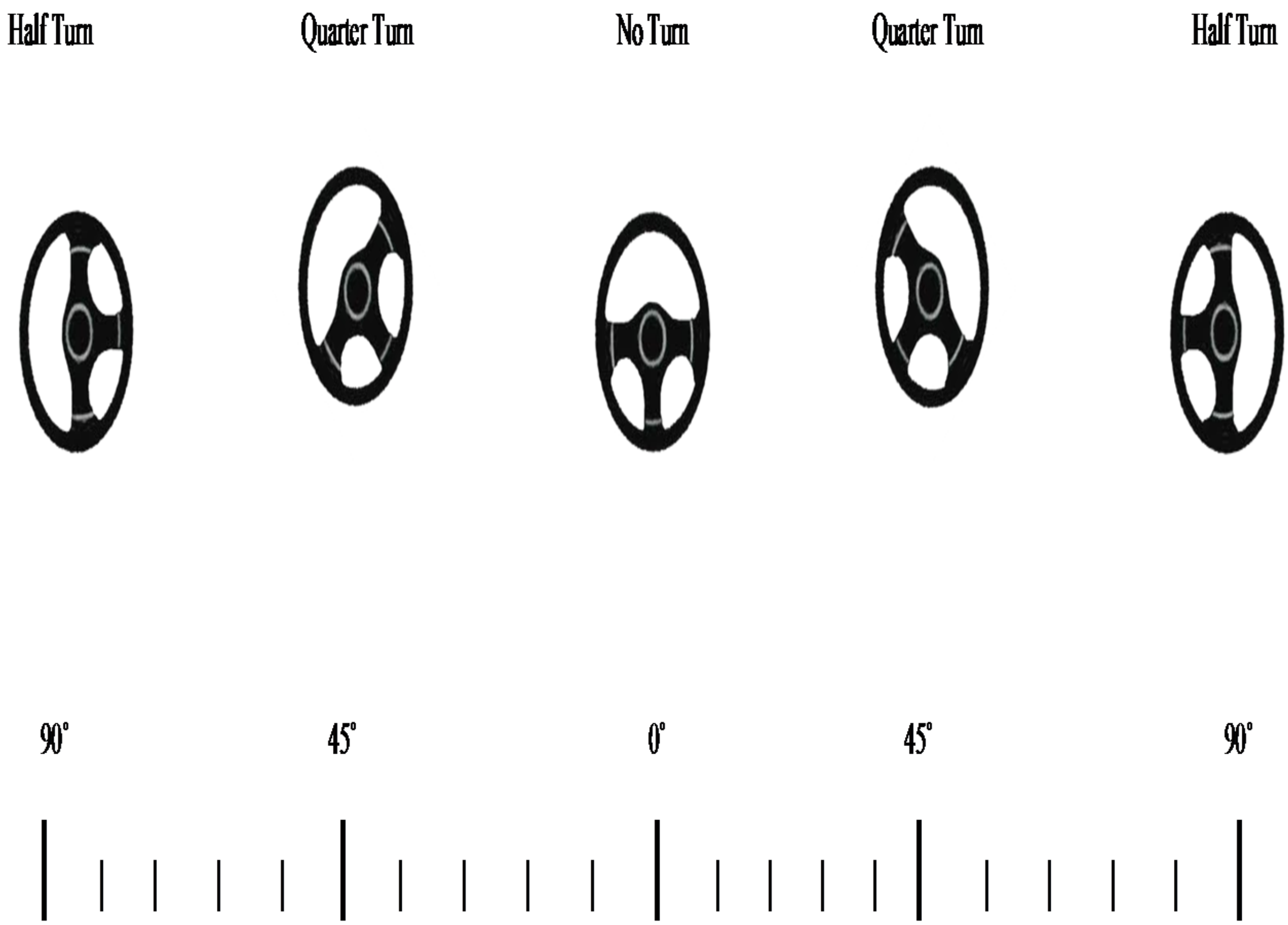
APPENDIX E
DRIVING COURSE



APPENDIX F
OBSERVATIONAL CHECKLIST

LEFT TURN

RIGHT TURN



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