# A Literature Review on Reaction Time

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Reaction time has a been a favorite subject of experimental psychologists since the middle of the nineteenth century (see Deary *et al.*, 2011). However, many of these papers are hard to understand for the beginning student. In this review, I have summarized the major literature conclusions that are applicable to undergraduate laboratories, with apologies to reaction time researchers for omissions and oversimplifications.

## Kinds of Reaction Time Experiments

Psychologists have named three basic kinds of reaction time experiments (Luce, 1986; Welford, 1980):

In **simple** reaction time experiments, there is only one stimulus and one response. 'X at a known location,' 'spot the dot,' and 'reaction to sound' all measure simple reaction time.

In **recognition** reaction time experiments, there are some stimuli that should be responded to (the 'memory set'), and others that should get no response (the 'distractor set'). There is still only one correct response. 'Symbol recognition' and 'tone recognition' are both recognition experiments.

In **choice** reaction time experiments, the user must give a response that corresponds to the stimulus, such as pressing a key corresponding to a letter if the letter appears on the screen. In a pure choice reaction time, the sequence of stimuli types is random. The *Reaction Time* program does not use this type of experiment because the response is always pressing the spacebar.

**Serial** reaction time is a variant of choice reaction time in which the order of stimulus types is not random. Instead, a stimulus of type y is likely to follow a stimulus of type x. The subject can become faster and faster with practice because he learns these sequences and begins to anticipate which stimulus will be presented next. The serial reaction time literature is reviewed by Schwarb and Schumacher (2012).

## Mean Simple Reaction Times

For about 120 years, the accepted figures for mean simple reaction times for college-age individuals have been about 190 ms (0.19 sec) for light stimuli and about 160 ms for sound stimuli (Galton, 1899; Fieandt *et al.*, 1956; Welford, 1980; Brebner and Welford, 1980). However, Eckner *et al.* (2010) reported that the reaction times of NCAA football players averaged 0.203 sec when determined with a simple falling meter stick but 0.268 sec when measured with a computer. Reaction times measured at Clemson are usually closer to 0.268 sec for a simple visual stimulus.

## Reaction Times in Simple vs. Recognition vs. Choice Experiments

The reaction time pioneer was Donders (1868), who showed that a simple reaction time is shorter than a recognition reaction time, and that the choice reaction time is longest of all. O'Shea and Bashore (2012) reviewed these early studies. Laming (1968) concluded that simple reaction times averaged 220 msec but recognition reaction times averaged 384 msec. This is in line with many studies concluding that a complex stimulus (e.g., several letters in symbol recognition vs. one letter) elicits a slower reaction time (Brebner and Welford, 1980; Teichner and Krebs, 1974; Luce, 1986). An example very much like our experiment was reported by Surwillo (1973), in which reaction was faster when a single tone sounded than when either a high or a low tone sounded and the subject was supposed to react only when the high tone sounded. Miller and Low (2001) determined that the time for motor preparation (e.g., tensing muscles) and motor response (in this case, pressing the spacebar) was the same in all three types of reaction time test, implying that the differences in reaction time are due to processing time.

By the way, professional psychologists doing these experiments typically employ about 20 people doing 100-200 reaction times each...per treatment (Luce, 1986, Ch. 6)! Sanders (1998, p. 23) recommends an adequate period of practice, and then collection of 300 reaction times per person. Our experiments of 3 or 4 people doing 10 reaction times each are very small. Whelan (2008) has an extensive series of recommendations on how to analyze reaction time data.

More complex *responses* also elicit slower reaction times. Henry and Rogers (1960) proposed the "memory drum" theory: that more complex responses require more stored information, and hence take longer. The status of this theory was reviewed by Klapp (2010).

**Numer of possible valid stimuli.** Several investigators have looked at the effect of increasing the number of possible stimuli in recognition and choice experiments. Hick (1952) found that in choice reaction time experiments, response was proportional to log(N), where N is the number of different possible stimuli. In other words, reaction time rises with N, but once N gets large, reaction time no longer increases so much as when N was small. This relationship is called "Hick's Law." Sternberg (1969) maintained that in recognition experiments, as the number of items in the memory set increases, the reaction time rises proportionately (that is, proportional to N, not to log N). Reaction times ranged from 420 msec for 1 valid stimulus (such as one letter in symbol recognition) to 630 msec for 6 valid stimuli, increasing by about 40 msec every time another item was added to the memory set. Nickerson (1972) reviewed several recognition studies and agreed with these results.

## Type of Stimulus

Many researchers have confirmed that reaction to sound is faster than reaction to light, with mean auditory reaction times being 140-160 msec and visual reaction times being 180-200 msec (Galton, 1899; Woodworth and Schlosberg, 1954; Fieandt *et al.*, 1956; Welford, 1980; Brebner and Welford, 1980). Perhaps this is because an auditory stimulus only takes 8-10 msec to reach the brain (Kemp *et al.*, 1973), but a visual stimulus takes 20-40 msec (Marshall *et al.*, 1943). Reaction time to touch is intermediate, at 155 msec (Robinson, 1934). Differences in reaction time between these types of stimuli persist whether the subject is asked to make a simple response or a complex response (Sanders, 1998, p. 114). Saville *et al.* (2012) found that people who had variable reaction times to a visual stimulus also had variable reaction times to an auditory stimulus.

## Stimulus Intensity

Froeberg (1907) found that visual stimuli that are longer in duration elicit faster reaction times, and Wells (1913) got the same result for auditory stimuli.

Pioron (1920) and Luce (1986) reported that the weaker the stimulus (such as a very faint light) is, the longer the reaction time is. However, after the stimulus gets to a certain strength, reaction time becomes constant.

Hsieh *et al.* (2007) found that simulated vibration of a computer monitor increased reaction times to stimuli presented on the monitor, worsened error rates, and caused more visual fatigue. In an application to Web site design, Tuch *et al.* (2009) found that visually complex Web sites increased user arousal (and stress) but slowed reaction times. Kohfeld (1971) found that the difference between reaction time to light and sound could be eliminated if a sufficiently high stimulus intensity was used.

## Other Factors Influencing Reaction Time

The type of reaction time experiment, type of stimulus, and stimulus intensity are basic features of any reaction time experiment, but there are still many factors affecting reaction time.
**Arousal.** One of the most investigated factors affecting reaction time is 'arousal' or state of attention, including muscular tension. Reaction time is fastest with an intermediate level of arousal, and deteriorates when the subject is either too relaxed or too tense (Welford, 1980; Broadbent, 1971; Freeman, 1933).

Etnyre and Kinugasa (2002) found that subjects who had to react to an auditory stimulus by extending their leg had faster reaction times if they performed a 3 second isometric contraction of the leg muscles prior to the stimulus. You might expect that the muscle contraction itself would be faster (because the muscle was warmed up, etc.), but what was surprising was that the precontraction part of the reaction time was shorter too. It was as if the isometric contraction allowed the brain to work faster. The same conclusion was reached by Masanobu and Choshi (2006). They found that moderate muscular tension (10% of maximum) shortened the *precontraction* reaction times of subjects who were asked to extend either their left or right leg in a choice reaction time task. Again, it seemed that muscular tension allowed the brain to work faster. Ironically, muscular tension did not affect movement time. Davranche *et al.* (2006) also concluded that exercise improved reaction time by increasing arousal. VaezMousavi *et al.* (2009) measured arousal in a continuous performance task by skin conductance, and found that while some subjects showed the traditional pattern in the graph above, others showed the opposite trend. In general, reaction time tended to improve as arousal increased. Anxiety is not necessarily bad. Martinie *et al.* (2010) found that being forced to write an essay defending opinions that the writer did not really share actually improved reaction time, possibly due to increased arousal. Anxious personality types showed faster reaction times to threatening faces, and could quickly process more threatening faces at once (Richards *et al.,* 2011).

**Relevance of Stimulus to Survival.** Boesveldt *et al.* (2010) noted that unpleasant odors (such as from spoiled food) might have great relevance to survival and health. They found that reaction time to unpleasant food odors was faster and more accurate than reaction to pleasant odors and to non-food odors.

**Age.** An early study (Galton, 1899) reported that for teenagers (15-19) mean reaction times were 187 msec for light stimuli and 158 ms for sound stimuli. Reaction times may be getting slower, because we hardly ever see a Clemson freshman (or professor) who is that fast. Simple reaction time shortens from infancy into the late 20s, then increases slowly until the 50s and 60s, and then lengthens faster as the person gets into his 70s and beyond (Welford, 1977; Jevas and Yan, 2001; Luchies *et al.*, 2002; Rose *et al.*, 2002; Der and Deary, 2006). In other words, contrary to their fervent belief, adolescents will probably have slower reaction times than adults (Riddervold *et al.*, 2008; Van Damme and Crombez, 2009). Luchies *et al.*(2002) also reported that this age effect was more marked for complex reaction time tasks, and Der and Deary (2006) concurred. Reaction time also becomes more variable with age (Hultsch *et al.*, 2002; Gorus *et al.*, 2008) and with Alzheimer's disease (Gorus *et al.,* 2008). MacDonald *et al.* (2008) found that reaction time variability in older adults was usually associated with slower reaction times and worse recognition of stimuli, and suggested that variability might be a useful measure of general neural integrity. Welford (1980) speculates on the reason for slowing reaction time with age. It is not just simple mechanical factors like the speed of nervous conduction. It may be the tendency of older people to be more careful and monitor their responses more thoroughly (Botwinick, 1966). When troubled by a distraction, older people also tend to devote their exclusive attention to one stimulus, and ignore another stimulus, more completely than younger people (Redfern *et al.*, 2002). Older people also seem to be better than younger ones at reacting to targets hidden by visual distraction because they look for known features of the targets (Whiting *et al.*, 2013). If the targets' features are unpredictable, this effect disappears. Myerson *et al.* (2007) found that older adults were as adept as younger people at assimilating information, but they did take longer to react. Lajoie and Gallagher (2004) found that old people who tend to fall in nursing homes had a significantly slower reaction time than those that did not tend to fall.

**Gender.** At the risk of being politically incorrect, in almost every age group, males have faster reaction times than females, and female disadvantage is not reduced by practice (Noble *et al.*, 1964; Welford, 1980; Adam *et al.*, 1999; Dane and Erzurumlugoglu, 2003; Der and Deary, 2006). The last study is remarkable because it included over 7400 subjects. Bellis (1933) reported that mean time to press a key in response to a light was 220 msec for males and 260 msec for females; for sound the difference was 190 msec (males) to 200 msec (females). In comparison, Engel (1972) reported a reaction time to sound of 227 msec (male) to 242 msec (female). However, things may be changing--Silverman (2006) reported evidence that the male advantage in visual reaction time is getting smaller (especially outside the US), possibly because more women are participating in driving and fast-action sports. Spierer *et al.* (2010) reported that when male soccer players were compared with female lacrosse players, males were able to respond faster to both visual and auditory stimuli. They said that the male advantage was greatest when using visual stimuli. Botwinick and Thompson (1966) found that almost all of the male-female difference was accounted for by the lag between the presentation of the stimulus and the beginning of muscle contraction. Muscle contraction times were the same for males and females. In a surprising finding, Szinnai *et al.* (2005) found that gradual dehydration (loss of 2.6% of body weight over a 7-day period) caused females to have lengthened choice reaction time, but males to have *shortened* choice reaction times. Adam *et al. (*1999) reported that males use a more complex strategy than females. Barral and Debu (2004) found that while men were faster than women at aiming at a target, the women were more accurate. Bayless *et al.* (2012) found that when a choice reaction time task was made more challenging for rats by weak stimuli and distraction, male rats tended to "jump the gun" and make premature responses, but female rats were more likely to miss valid stimuli. Note that this study used rats, not humans. Jevas and Yan (2001) reported that age-related deterioration in reaction time was the same in men and women.

**Left vs. right hand.** The hemispheres of the cerebrum are specialized for different tasks. The left hemisphere is regarded as the verbal and logical brain, and the right hemisphere is thought to govern creativity, spatial relations, face recognition, and emotions, among other things. Also, the right hemisphere controls the left hand, and the left hemisphere controls the right hand. This has made researchers think that the left hand should be faster at reaction times involving spatial relationships (such as pointing at a target). The results of Boulinquez and Bartolomy (2000) and Bartolomy and Boulinquez (2001 and 2002) all supported this idea. Dane and Erzurumluoglu (2003) found that in handball players, the left-handed people were faster than right-handed people when the test involved the left hand, but there was no difference between the reaction times of the right and left handers when using the right hand. Finally, although right-handed male handball players had faster reaction times than right-handed women, there was no such sexual difference between left-handed men and women. The authors concluded that left-handed people have an inherent reaction time advantage. In an experiment using a computer mouse, Peters and Ivanoff (1999) found that right-handed people were faster with their right hand (as expected), but left-handed people were equally fast with both hands. The preferred hand was generally faster. However, the reaction time advantage of the preferred over the non-preferred hands was so small that they recommended alternating hands when using a mouse. Derakhshan (2006 and 2009) cautions that preferred hand is not always a good guide to the dominant hemisphere. In most people, a dominant (and faster) right hand implies a dominant left hemisphere. However, he found that a minority (20%-25%) of right-handed people actually had a dominant *right* hemisphere, and that reaction time on the right side of the body was slower in these people because commands had to originate in the right hemisphere and then cross over to the left hemisphere, and then get to the right hand. In other words, the side of the body with the longer reaction time (not always the side with the nonpreferred hand) is the side with the dominant hemisphere. Bryden (2002), using right-handed people only, found that task difficulty did not affect the reaction time difference between the left and right hands. Miller and Van Nes (2007) found that responses involving both hands were faster when the stimulus was presented to both hemispheres of the brain simultaneously. Because the right (emotional) hemisphere is supplied with input by the left eye, it might be suspected that the left visual field would be the fastest at identifying emotions. Alves *et al.* (2009) confirmed that faces showing happiness or fear were identified most rapidly when presented to the left visual field (e.g., and examined by the right hemisphere), and that neutral expressions were detected most rapidly by the right visual field. Godard and Fiori (2010) found that men are just as accurate at face recognition as women, but that women were faster. They also found that men were more strongly "lateralized" than women, with dominance of the right cerebral hemisphere. Musicians appear to have hemispheres that are more equally capable of paying attention to stimuli than non-musicians, and to have faster reaction times as well (Patston *et al.*, 2007).

**Direct vs. Peripheral Vision.** Brebner and Welford (1980) cite literature that shows that visual stimuli perceived by different portions of the eye produce different reaction times. The fastest reaction time comes when a stimulus is seen by the cones (when the person is looking right at the stimulus). If the stimulus is picked up by rods (around the edge of the eye), the reaction is slower. Ando *et al.*, 2002 found that practice on a visual stimulus in central vision shortened the reaction time to a stimulus in peripheral vision, and *vice versa.*

**Practice and Errors.** Sanders (1998, p. 21) cited studies showing that when subjects are new to a reaction time task, their reaction times are less consistent than when they've had an adequate amount of practice. Also, if a subject makes an error (like pressing the spacebar before the stimulus is presented), subsequent reaction times are slower, as if the subject is being more cautious. Koehn *et al.* (2008) also found that "accusing" subjects of making an error slowed their processing of the next stimulus more than indicating that they had made a correct choice. Ando *et al.* (2002) found that reaction time to a visual stimulus decreased with three weeks of practice, and the same research team (2004) reported that the effects of practice last for at least three weeks. Fontani *et al.* (2006) showed that in karate, more experienced practitioners had shorter reaction times, but in volleyball, the inexperienced players had shorter reaction times (and made more errors too). Visser *et al.* (2007) found that training on a complex task both shortened reaction time and improved accuracy. Rogers *et al.* (2003) found that training older people to resist falls by stepping out to stabilize themselves did improve their reaction time.

**Fatigue.** Welford (1968, 1980) found that reaction time gets slower when the subject is fatigued. Singleton (1953) observed that this deterioration due to fatigue is more marked when the reaction time task is complicated than when it is simple. Mental fatigue, especially sleepiness, has the greatest effect. Kroll (1973) found no effect of purely muscular fatigue on reaction time. Philip *et al.* (2004) found that 24 hours of sleep deprivation lengthened the reaction times of 20–25-year-old subjects, but had no effect on the reaction times of 52-63 year old subjects. Van den Berg and Neely (2006) found that sleep deprivation caused subjects to have slower reaction times and to miss stimuli over a test period that lasted two hours. Cote *et al.* (2009) had the same conclusions about two days of restricted sleep, and also found that the more restricted sleep was, the worse the deterioration in reaction time, and the subjects seemed to be compensating for this by more mental effort (measured by high-frequency EEG waves). Takahashi *et al.* (2004) studied workers who were allowed to take a short nap on the job, and found that although the workers thought the nap had improved their alertness, there was no effect on choice reaction time.  Also see the study by Jauch-Chara *et al.* under "Fasting."

**Fasting.** Three days without food does not decrease reaction time, although it does impair capacity to do work (Gutierrez *et al.*, 2001). These results were confirmed by Cheatham *et al.* (2009) found that six months of calorie-limited diets with either high and low carbohydrates did not affect reaction time or any other cognitive measure. Diets high in carbohydrates did result in depressed mood. On the other hand, Jauch-Chara *et al.* (2010) found that sleep deprivation lengthened reaction time and so did acute hypoglycemia, but sleep deprivation and hypoglycemia together did not cause worse effects than either of them separately.

**Distraction.** Welford (1980) and Broadbent (1971) reviewed studies showing that distractions increase reaction time. Trimmel and Poelzl (2006) found that background noise lengthened reaction time by inhibiting parts of the cerebral cortex. Richard *et al.* (2002) and Lee *et al.* (2001) found that college students given a simulated driving task had longer reaction times when given a simultaneous auditory task. They drew conclusions about the safety effects of driving while using a cellular phone or voice-based e-mail. Horrey and Wickens (2006) and Hendrick and Switzer (2007) had similar conclusions about cell phone use while driving, and said that hands-free phones did not improve reaction time performance. Reaction time suffered more than tasks like keeping in the right lane. Redfern *et al.* (2002) found that subjects strapped to a platform that periodically changed orientation had slowed reaction time before and during platform movement. The reaction time to auditory stimuli was more affected than response to visual stimuli. Hsieh *et al.* (2007) found that simulated vibration of a computer monitor increased reaction times to stimuli presented on the monitor, worsened error rates, and caused more visual fatigue. The effect of distraction may depend on emotional state and prior experiences. Reed and Antonova (2007) frustrated some subjects by giving them unsolvable problems, and then tested the reaction times of all the subjects with distraction. Subjects who had been given the difficult problems were more slowed and distracted than subjects who had not been frustrated before the reaction time measurement. Similar results were cited by Gerdes *et al.* (2008), who found that subjects who were phobic about spiders had their reaction time slowed more by distracting pictures of spiders than by distracting pictures of objects like flowers and mushrooms. This was caused by the phobic subjects' failure to look away from the spider pictures as fast as they looked away from the other pictures. Martinie *et al.* (2010) found that being forced to write an essay defending opinions that the writer did not really share actually improved reaction time, possibly due to increased arousal. Kunde *et al.* (2011) found that basketball novices were slower to indicate the direction in which a ball was being passed if the player looked in one direction while passing in another (a head fake). This happened whether the observer had a fast or a slow reaction time. Older people seem to be better than younger ones at reacting to targets hidden by visual distraction because they have a better ability to spot known features of the targets (Whiting *et al.*, 2013).

**Warnings of Impending Stimuli.** Brebner and Welford (1980) report that reaction times are faster when the subject has been warned that a stimulus will arrive soon. In the *Reaction Time* program, the delay is never more than about 3 sec, but these authors report that even giving 5 minutes of warning helps. Bertelson (1967) found that if the warning was longer than about 0.2 sec., the shorter the warning was, the faster reaction time was. This effect probably occurs because attention and muscular tension cannot be maintained at a high level for more than a few seconds (Gottsdanker, 1975). Jakobs *et al.* (2009) found that stimuli that were predictable elicited faster reaction times, probably because of decreased computational load on the brain. Also, warning of the stimulus can increase the number of erroneous responses given before the stimulus (O'Neill and Brown, 2007). However, Perruchet *et al.* (2006) said that when two events are associated with one another, conscious expectation of the second event may actually slow reaction to it. They considered this evidence that expectation of an event and reaction to it are independent processes. This view was disputed by Mitchell *et al.* (2010), who found that when visual stimuli were reliably preceded by tones, reaction time to the visual stimulus was faster than when many false-alarm tones had been given without being followed by a visual stimulus. McKeown *et al.* (2010) found that warnings of an impending collision in a driving simulation brought faster reaction times when they were realistic and dramatic (recorded screeching of brakes) rather than a text or speech message.

**Alcohol.** Moskowitz and Fiorentino (2000) review the impairing effects of alcohol on reaction time. Kruisselbrink *et al.* (2006) found that adult females who drank from one to six cans of beer did *not* suffer delayed reaction times the next morning, although they made more errors on a choice reaction time task. Hernandez *et al.* (2007) found that the slowing of reaction time by alcohol was due to a slowing of muscle activation, not muscle action. Fillmore and Blackburn (2002) found that subjects who had drunk an impairing dose of alcohol reacted faster when they were warned that this was enough alcohol to slow their reaction time. Unwarned subjects who drank suffered more decreased reaction times. However, the warned subjects were also less inhibited and careful in their responses. Even subjects who drank some nonalcoholic beverage and then were warned (falsely) about impairment by alcohol reacted faster than unwarned subjects who drank the same beverage.

**Order of Presentation.** Welford (1980), Laming (1968) and Sanders (1998) observed that when there are several types of stimuli, reaction time will be faster where there is a 'run' of several identical stimuli than when the different types of stimuli appear in mixed order. This is called the "sequential effect." Hsieh (2002) found that the shifting of attention between two different types of tasks caused an increase in reaction time to both tasks.

**Breathing Cycle.** Buchsbaum and Calloway (1965) found that reaction time was faster when the stimulus occurred during expiration than during inspiration.

**Finger Tremors.** Brebner and Welford (1980) report that fingers tremble up and down at the rate of 8-10 cycles/sec, and reaction times are faster if the reaction occurs when the finger is already on the 'downswing' part of the tremor.

**Attentional Blink.** Hanslmayr *et al.* (2011) discussed the idea that the brain has regular oscillations of attention that can be linked to the brain's alpha waves. Shortly after a stimulus is presented, the brain is in "internal processing mode" and has reduced ability to perceive a new stimulus. This phenomenon is called "attentional blink" and is most obvious when the second stimulus is presented from 100-500 ms after the first stimulus.

**Affective Priming.** Affective priming is the phenomenon that a subject can rate a word as either emotionally positive or negative more quickly if first shown a picture with the same emotional connotation (e.g., reaction times are faster to a pleasant word if the subject is "primed" by exposure to a pleasant picture first). If shown a pleasant picture followed by an unpleasant word, reaction times are slower, as if the subject is distracted by the discordance between the word and picture. Zhang *et al.* (2012) reviewed the literature on affective priming, verified that it does occur, and that it is influenced by the degree of arousal of the subject.

**Personality Type.** Brebner (1980) found that extroverted personality types had faster reaction times, and Welford (1980) and Nettelbeck (1973) said that anxious personality types had faster reaction times. Lenzenweger (2001) found that the reaction times of schizophrenics was slower than those of normal people, but their error rates were the same. Robinson and Tamir (2005) found that neurotic college students had more variable reaction times than their more stable peers.

**Exercise.** Exercise can affect reaction time. Welford (1980) found that physically fit subjects had faster reaction times, and both Levitt and Gutin (1971) and Sjoberg (1975) showed that subjects had the fastest reaction times when they were exercising sufficiently to produce a heartrate of 115 beats per minute. Kashihara and Nakahara (2005) found that vigorous exercise did improve choice reaction time, but only for the first 8 minutes after exercise. Exercise had no effect on the percent of correct choices the subjects made. Nakamoto and Mori (2008) found that college students who played basketball and baseball had faster reaction times than sedentary students. At least for baseball, the more sports experience the students had, the faster their reaction times were to baseball-specific stimuli. Davranche *et al.* (2006) concluded that exercise on a stationary bicycle improved reaction times. On the other hand, McMorris *et al.* (2000) found no effect of exercise on reaction time in a test of soccer skill, and Lemmink and Visscher (2005) found that choice reaction time and error rate in soccer players were not affected by exercise on a stationary bicycle. Pesce *et al.* (2007) concurred that exercise did not improve the reaction time of soccer players. Collardeau et al. (2001) found no post-exercise effect in runners, but did find that exercise improved reaction time *during* the exercise. They attributed this to increased arousal during the exercise. See the "Arousal" section for effect of exercise also. Lord *et al.* (2006) found that water exercise over a period of 22 weeks did *not* improve the reaction times of elderly people. Snowden *et al.* (2011) reviewed 30 large studies and found that physical exercise had inconclusive effects on the reaction time of elderly adults living in a community setting. The authors also reported that exercise had inconclusive results on attention, general cognition, memory, and several other measures of mental function. The effects of exercise on reaction time were also reviewed by McMorris and Grayden (2000) and Tomporowski (2003).

**Punishment, Stress, and Threats.** Shocking a subject when he reacts slowly does shorten reaction time (Johanson, 1922; Weiss, 1965). Simply making the subject feel anxious about his performance has the same effect, at least on simple reaction time tasks (Panayiotou, 2004). Mogg *et al.* (2008) found that it might be hard to disentangle the effects of threat-induced anxiety from the simple distraction that the threat was causing. In other words, even a non-threatening stimulus can cause distraction and slow reaction time, but not by causing anxiety. Verlasting (2006) found that deployment to Iraq caused soldiers to have shorter reaction times, but also increased tension and reduced proficiency at tasks requiring memory and attention. Feenstra *et al.* (2012) found that adults responded more quickly than 15-year-olds to questions about risky situations in which the user had to indicate whether doing something was a good or bad idea (e.g., "Keep both hands on the wheel when driving" vs. "Tow a bike with a moped.") In any timed task, there are speed-accuracy tradeoffs. For example, if speed is rewarded more than accuracy, reaction times will be shorter than when heavy penalties are attached to making mistakes. Simen *et al.* (2009) produced a model of this situation, and found that human subjects adjusted their speed and accuracy to optimize their rewards, just as the model had predicted.

**Stimulant Drugs.** Caffeine has often been studied in connection with reaction time. Lorist and Snel (1997) found that moderate doses of caffeine decreased the time it took subjects to find a target stimulus and to prepare a response for a complex reaction time task. Durlach *et al.* (2002) found that the amount of caffeine in one cup of coffee did reduce reaction time and increase ability to resist distraction, and did so within minutes after consumption. McLellan *et al.* (2005) found that soldiers in simulated urban combat maintained their marksmanship skills and their reaction times through a prolonged period without sleep better when given caffeine. Liguori *et al.* (2001) found that caffeine can reduce the slowing effect of alcohol on reaction time, but can't prevent other effects such as body sway. On the other hand, Linder (2001), using our software and a "Spot-the-Dot" test, found that drinking one can of either a caffeinated or a caffeine-free cola had no detectable effect on reaction time. Froeliger *et al.* (2009) found that smokers who were abstaining from cigarettes had faster reaction times on a recognition reaction time task when they were wearing a nicotine patch, and even nonsmokers had increased accuracy (implying better memory) when they were wearing nicotine patches. Kleemeier *et al.* (1956) found that administering an amphetamine-like drug to a group of elderly men did not make their reaction times faster, although it did make their physical responses more vigorous. On the other hand, O'Neill and Brown (2007) found that amphetamine and a drug called KW-6002 speeded reaction times and also increased the frequency of erroneous responses before the stimulus in the hyper-alert participants (rats). Methylphenidate is a stimulant drug that is used in treatment of attention deficit hyperactivity disorder (ADHD). If children with ADHD were given methylphenidate (which reduces lapses in attention), their times on a recognition reaction time task were both shorter and less variable (Spencer *et al.,* 2009).

**Depressant Drugs.** Dassanayake *et al.* (2012) found that patients treated in the hospital for overdoses of depressant drugs such as opioids and antipsychotics (but who were deemed ready for discharge) had significantly slowed reaction times compared to patients who were being treated for overdoses of other types of drugs. They also had worse memories and more impulsive behavior.

**Intelligence.** The tenuous link between intelligence and reaction time is reviewed in Deary *et al.* (2001). Serious mental retardation produces slower and more variable reaction times. Among people of normal intelligence, there is a slight tendency for more intelligent people to have faster reaction times, but there is much variation between people of similar intelligence (Nettelbeck, 1980). The speed advantage of more intelligent people is greatest on tests requiring complex responses (Schweitzer, 2001). Kaufman *et al.* (2011) found that while people with high-normal intelligence could solve reasoning tasks more successfully than people of low-normal intelligence, they were not necessarily faster. Lee and Chabris (2013) investigated the ability of more intelligent people to respond faster to two stimuli that were very close together, and concluded that the superior ability of intelligent people resided in the processing time of the brain, not in faster stimulus perception or response of the muscles.

**Learning Disorders.** Miller and Poll (2009) found that college students with a history of language and/or reading difficulties had slower reaction times. Within the affected group of students, better language skills were associated with faster reaction times.

**Brain Injury.** As might be expected, brain injury slows reaction time, but different types of responses are slowed to different degrees (reviewed in Bashore and Ridderinkhof, 2002). Collins *et al.* (2003) found that high school athletes with concussions and headache a week after injury had worse performance on reaction time and memory tests than athletes with concussions but no headache a week after injury. Kontos *et al.* found that concussed high school and college athletes had slower reaction times as much as 14 days after injury. Eckner *et al.* (2010) cited several papers that studied the slowing of reaction time after concussion. Soldiers and contractors in Iraq who suffered mild traumatic brain injury showed a marked impairment of reaction time when measured within 72 hours of the injury (Leuthcke *et al.*, 2011). However, Kaminski *et al.* (2008) found that hitting the ball with the head in soccer (and possibly suffering injury from it) had no significant effect on the reaction time of female soccer players.

**Illness**. Minor upper respiratory tract infections slow reaction time, make mood more negative, and cause disturbance of sleep (Smith *et al.*, 2004).

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