UNIVERSITY OF CENTRAL OKLAHOMA

Edmond, Oklahoma

Jackson College of Graduate Studies

Developing a Methodology for Manipulating Spontaneous Blinks

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of requirements for

the degree of

MASTER OF ARTS IN EXPERIMENTAL PSYCHOLOGY

By

YASMIN SHIRALI

Edmond, Oklahoma

2017

DEVELOPING A METHODOLOGY FOR MANIPULATING SPONTANEOUS BLINKS

A THESIS

APPROVED FOR THE DEPARTMENT OF PSYCHOLOGY

August 2nd, 2017

Dr. Caleb Lack, Committee Chair

Dr. Tephillah Jeyaraj-Powell, Committee Member

Dr. Thomas Hancock, Committee Member

Dr. Kirk Webster, Committee Member

Abstract

While blinking is necessary for ocular protection and lubrication, people blink much more than is necessary for routine ocular maintenance. These extra, spontaneous blinks are extremely difficult to manipulate and thus, have remained somewhat of a mystery. In order to determine the effects of spontaneous blinks, a methodology to manipulate them naturally must be created. The aim of this study was to develop such methodology using videos of animated speakers displaying high and low blink rates, and determine whether this influenced participant blink rates. It was expected that watching videos of a speaker's face would manipulate blink rate. It was also expected that participants would imitate the speaker's blink timing and blink immediately after the speaker blinks, called blink entrainment. Participants watched four videos, two featuring an animated speaker with a high blink rate, and two featuring the same animated speaker with a low blink rate. In between the speaker videos, participants completed ten trials of several variations of a lexical decision task. The speaker videos provided instructions on how to complete each of these tasks. A Wilcoxon signed-rank test showed that the differences between participant blink rates across the high blink rate and the low blink rate were significant ($Z = -3.16$, $p = .002$). Participants blinked more frequently while watching the high blink rate videos than when watching the low blink rate videos. A Wilcoxon signed-rank test also showed a significant difference between entrainment blinks and non-entrainment blinks in the high blink rate condition ($Z = -3.65$, $p = .001$), and the low blink rate condition ($Z = -2.21$, $p = .027$). These results indicate that a standardized methodology for manipulating spontaneous blinks is possible. With the use of the animated speaker videos, spontaneous blinks can be manipulated.

Developing a Methodology for Manipulating Spontaneous Blinks

A lot can happen in the blink of an eye: a warning sign from a territorial animal, a falling object, and micro-expressions are just some rapidly-occurring events that could lead to death if missed. For example, blinking at the wrong time could make a person oblivious to the micro-expressions of an angry enemy, which would have served as warning signs for future danger had they been seen. Vital information necessary for survival can be lost during eye-blinks. Why then, has blinking not been negatively selected? More importantly, why would people blink more than necessary?

Blinking results in extensive losses of visual input, with people losing anywhere from 200-400ms of information per blink (Nakano, Yamamoto, Kitajo, Takahashi, & Kitazawa, 2009). Although a seemingly small amount of time, this is enough to miss vital information from the environment, useful for functioning and survival. While blinking is necessary for ocular protection and lubrication, people blink much more than necessary for routine ocular maintenance. Lubricating and cleansing the eye can be accomplished in as little as 2-4 blinks per minute (Pivik & Dykman, 2004; Evinger, 1995; Ponder & Kennedy, 1927), yet the average person blinks about 15-20 times per minute (Nakano, Kato, Morito, Itoi, & Kitazawa, 2013). These “extra” blinks are called spontaneous blinks and little is currently known about their purpose or purposes.

Over the past century, an increasing amount of research has focused on the purpose and physiology of blinking. At its core, a blink is the bilateral contraction of the orbicularis muscles of both eyes (Deuschl & Goddemeier, 1998). As more research has investigated blinking behaviors, three types of blinks have been observed: reflexive, voluntary, and spontaneous

(Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015). While all blinks distribute a tear on the ocular surface and protect the eye from environmental factors (Schaefer, Schaefer, Abib, & José, 2009), each type of blink differs in amplitude and duration, and each serves a particular purpose (Orchard & Stern, 1991; Agostino et al., 2008; Yoon, Chung, Song, & Park, 2005; Volkmann, Riggs, Ellicott, & Moore, 1982).

Reflexive blinks are involuntary responses that protect the eyes from external stimuli (Hall, 1945; Stern, Walrath, & Goldstein, 1984), such as debris in the wind or incoming objects. These blinks not only occur in response to visual stimuli, they occur as responses to loud sounds or other sudden and intense events (Stern, Walrath, & Goldstein, 1984). The magnitude of reflexive blinks is stimulus-dependent and controlled by the nervous system (Evinger, 1995). If a stimulus is very weak, the reflexive blink response may only elicit a partial closure of the upper eyelid, while a strong stimulus will elicit full closure. Reflexive blinks are also triggered by dryness of the eyes, which maintains ocular lubrication (Evinger, 1995).

Voluntary blinks are similar to reflexive blinks in that they are responses to identifiable stimuli (Stern, Walrath, & Goldstein, 1984). Voluntary blinks, however, are not involuntary reflexes, but purposely initiated movements by the blinker in response to certain stimuli (e.g., instructions to blink from the eye doctor). Voluntary blinks tend to be longer in duration than other blinks (Matsuno, Ohyama, Ohi, Abe, & Sato, 2013) and have more consistent duration periods (VanderWerf, Brassinga, Reits, Aramideh, & de Visser, 2003). They can also be distinguished with electrooculography measurements, which show that voluntary blinks have the greatest amplitude compared to the other types of blinks (Yoon, Chung, Song, & Park, 2005).

Spontaneous blinks, sometimes called endogenous blinks, are all the other blinks that are not a) responses to obvious stimuli nor b) purposefully initiated by the blinker (Stern, Boyer, &

Schroeder, 1994). An individual's blink rate consists mostly of spontaneous blinks, with reflexive and voluntary blinks occurring much less frequently. Spontaneous blinks are shorter in duration than reflexive or voluntary blinks (Yoon, Chung, Song, & Park, 2005). They serve to lubricate the eye, but occur much more frequently than needed to accomplish this goal. It is therefore suspected that spontaneous blinks have additional important functions.

In order to examine whether spontaneous blinks have multiple functions, experimental manipulation is necessary. While a multitude of hypotheses on the role of spontaneous blinks have been made, most of the existing research is correlational and indirect. Ideas in science must be testable; if a hypothesis can never be tested, it can never be falsified, and progress is halted. Spontaneous blinks have not been directly manipulated, with good reason. Spontaneous blinks are only those that occur naturally without any obvious cause. If a participant is instructed in any way to blink or to inhibit a blink, then it is voluntary and not spontaneous blinks that are being tested, thus making spontaneous blinks extremely difficult to manipulate.

Before the effects of spontaneous blinks can be understood, it is necessary to develop a valid, generalizable methodology that can be used to test the many hypotheses that have been proposed on this topic. Because spontaneous blink rate is extremely variable within individuals, it is likely that the proper tools can be used to create a method that can increase or decrease spontaneous blink rate, and manipulate the specific timing of spontaneous blinks. The goal of this study, then, is to develop methodology for manipulating spontaneous blinks.

What We Know About Spontaneous Blinks

Spontaneous blinks (SBs) display a wide range of idiosyncrasies that give insight into their potential roles and benefits. Understanding the dynamic characteristics of spontaneous blinks and the environmental variables that elicit changes in blink rate are necessary for developing a valid methodology to manipulate them.

Spontaneous Blink Rates are Dynamic

Blink rate changes during conversation, during different types of activities, and even throughout the time of day, making them a dynamic process. Dynamic processes are typically seen when a benefit is gained from that process. For example, breathing maintains the balance of oxygen and carbon dioxide needed to live (Ward, 2005). The rate of breathing changes based on a person's physiological needs. During exercise, levels of carbon dioxide increase rapidly and the body requires more oxygen. The rate of breathing increases to provide more oxygen and restore the balance (Ward, 2005). The dynamic properties of SBs appear to work in much the same way.

For example, research has shown that people blink more frequently while watching uneventful scenes during a movie, as opposed to scenes containing action sequences (Nakano, Yamamoto, Kitajo, Takahashi, & Kitazawa, 2009). Likewise, people blink more during scenes in which the main character does not appear (Nakano et al., 2009). Without conscious awareness of doing so, people blink during moments which are not crucial to the story, or those where visual loss is not as potentially costly.

Spontaneous blinks also show incredible temporal precision. People blink at the same spots during scenes while watching a film. When multiple participants were videotaped at the same time, while watching a movie in a theatre-like room, their blinks became synchronized (Nakano et al., 2009). Participants blinked during the same moments—particularly when an actor finished a sentence, or when a door closed—moments that could be missed at no great cost.

Again, this happens non-consciously, as participants had no way to tell when other people were blinking.

Although there is little research in this area, this data does point to the same conclusion. That is, there appears to be a well-developed temporal component to SBs that reduces the cost of missing valuable visual input by triggering blinks during the least relevant moments in a particular environment. These temporal changes do not appear to be due to conscious decisions on the part of the individual (i.e., they are not deliberate blinks) and instead appear to be environmentally mediated.

Blinking and Communication

Spontaneous blinks show strong links to social components, and appear to play an essential role in communication. While engaged in conversation, people tend to mimic each other and coordinate certain behaviors and movements (Iacoboni, 2009). Spontaneous blinks are one of these often mimicked behaviors. In fact, after a few moments of speaking to one another, the blink rate of two speakers becomes synchronized (Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Newborns even mimic their mothers' blinks (Stel & Vonk, 2010; Kugiumutzakis, 1996). The fact that mimicking SBs occurs so early in life is indicative of the social significance of these blinks, and yet there is no definitive answer as to why this may be the case. Perhaps spontaneous blinks could be useful in facilitating social bonds, or even that mimicking blinks is particularly important for the feeling of belonging (De Gelder, 2006).

While watching a video-clip of a man's face while giving a speech, viewers blinked right after the speaker blinked; this effect was especially significant when the speaker was coming to a pause (i.e., finishing a sentence). Interestingly, this effect was not seen when participants saw the video with no accompanying audio, or when participants only listened to the speech without viewing the speaker. This led the researchers to draw the conclusion that spontaneous blinks are not simply triggered by mirror neurons, as they do not occur when people only view the speaker but are not provided with accompanying auditory information (Nakano, Yamamoto, Kitajo, Takahashi, & Kitazawa, 2009; Nakano & Kitazawa, 2010). Although SBs seem to be closely linked to language and often occur at the end of sentences, language is not necessary for the use of SBs in social situations.

Nonhuman primate species appear to use SBs for social reasons as well (Tada, Omori, Hirokawa, Ohira, & Tomonaga, 2013). A study recorded and analyzed blink rates for 71 species of nonhuman primates, and found that after controlling for body size and daylight, blink rate is positively correlated with group size. Blink rate frequencies rise as the number of members in a group increases, indicating a strong social benefit gained from SBs (Tada, Omori, Hirokawa, Ohira, & Tomonaga, 2013).

A further indication of the social aspects of SBs comes from the fact that people with autism do not exhibit the same blinking patterns as the neurotypical population. Many people with ASD suffer social deficits that prevent them from interacting the way healthy populations interact. The same researchers who found that people watching a video of a speaker blink right after the speaker blinked, further tested the social components of SBs by replicating that study using a population with autism spectrum disorder (ASD; Nakano, Kato, & Kitazawa, 2011). Social deficits are among the most common symptoms in people with autism. For example, people with ASD do not focus on people’s eyes when talking to or listening to them (Senju & Johnson, 2009). Using the same video clips, the researchers tested participants with ASD. Unlike the participants without autism, participants with it did not synchronize their blinks to those of the speaker. The more severe an individual’s ASD symptoms, the more their SBs deviated from the speaker's blinks. The authors suggest that the observed results may be due to temporal deficits observed in people with ASD, and that temporal patterns during conversation facilitate gaining rapport with the other person and facilitate social communication (Nakano, Kato, & Kitazawa, 2011). If a deficit in determining temporal patterns during conversation is the reason for the social deficits experienced by people with ASD, spontaneous blinks could be facilitating the use of these patterns in nonclinical populations.

The collective knowledge obtained from these studies indicates that social components are a huge part of spontaneous blinking, and could be one of the major benefits. However, if social communication is facilitated by several behaviors (e.g., imitating body movements), why would blinking also be needed? It could be that SBs also afford cognitive benefits in addition to social ones.

Spontaneous Blinks and Attention

Spontaneous blink rate is dependent on the amount of attention required from the task in which a person is engaged. When tasks require high levels of attention, SB rate decreases. Inversely, when tasks require little attention, SB rate is higher (Stern, Boyer, & Schroeder, 1994). So, spontaneous blinking may be a way to disengage attention (Sheline et. al, 2009).

Each time a person spontaneously blinks, there is a momentary deactivation of the dorsal attention network that controls spatial orientation and attention to a particular stimulus (Patak & Schnider, 2010). Simultaneously, there is an activation of the default-mode network, which reduces attention to goal-oriented tasks and increases wandering and daydreaming (Sheline et al., 2009). This change in the brain may help facilitate cognitive task disengagement and re-focusing attention (Nakano, Yamamoto, Kitajo, Takahashi, & Kitazawa, 2009). If spontaneous blinking is a way of disengaging and redirecting attention, it is likely that these blinks enhance cognitive performance. This is supported by not seeing such brain-based changes in voluntary or reflexive blinks (Guipponi, Odouard, Pinède, Wardak, & Hamed, 2014; Kato & Miyauchi, 2003).

Unfortunately, many research questions regarding SBs and their direct influence on performance cannot yet be answered. Without manipulation, it is particularly challenging to determine directionality: Is blink rate being changed by a person's level of concentration, or is concentration being enhanced by changing blink rates? To understand more about the directionality of the relationship between blinking and the brain, one must manipulate spontaneous blinks to observe the effects, if any, on the brain.

Perspectives and Hypotheses on Spontaneous Blinks

Although spontaneous blinks have not been successfully manipulated yet, many hypotheses on the role of SBs have been proposed. There are several views on both why these blinks occur so frequently and why they seem to occur during particular moments. An understanding of these views is important in order to construct a method that will be able to test the many predictions that exist concerning SBs.

Cost/Benefit Analysis of SBs

Blinking comes with two large costs: energy expenditure and loss of visual information. It is unknown exactly how much energy is required to blink. While it is likely of minimal energy expenditure, any behavior consuming unnecessary energy is typically phased out over time via evolutionary processes. Energy optimization is a consistent goal for living organisms, and this goal modifies behavior, even when the savings in energy are small (Selinger, O’Connor, Wong, & Donelan, 2015). In fact, it has been demonstrated that people continuously optimize energy expenditure while walking. People tweak small movements as they walk to reduce unnecessary losses of energy (Selinger, O’Connor, Wong, & Donelan, 2015). Spontaneous blinks likely operate in a similar way. Because SBs show so much variability without awareness from the blinker, it is likely that SB rate is constantly being optimized.

The greater cost of blinking is the loss of visual information. The visual system is extremely complex and well-developed, enough to detect minor changes in color, rapid movements, and miniscule changes in facial expressions (Öhman, Flykt, & Esteves, 2001; Shen, Wu, & Fu, 2012; Vrij & Mann, 2001). The duration of blinks is long enough to miss many of these events. It is highly unlikely that a behavior this costly would exist without the concurrent accrual of benefits that make it worthwhile.

Behaviors that are too costly to either maintain or increase fitness do not persist in a species (Trivers, 1971). When a species displays costly behavior, there is almost certainly a benefit that allows that behavior to persist. This cost/benefit approach prompts the question of what the benefits of SBs may be, given that the costs are quite obvious. However, to find the potential benefits of SBs, they must be experimentally manipulated.

Mental Tension Relief

The early work of Ponder and Kennedy (1927) demonstrated that blinking occurs more than is necessary, and suggested that blinks could be related to mental tension. Specifically, they suggested that blinking could be a mechanism by which to relieve nervous tension. This is the first hypothesis regarding why spontaneous blinks exist and how they are likely to contain a bigger benefit. A wide range of hypotheses about the role of spontaneous blinks have followed, but the one thing they have in common is their lack of testability.

Thirty years after Ponder and Kennedy (1927) proposed the relationship between blinks and mental tension, the question remained unanswered due to a lack of research experimentally addressing the difficult topic (Meyer, 1953). The topic of muscle tension and blinking was addressed again when researchers investigated the effect of muscular tension on blink rate (King & Michels, 1957). A relationship between muscle tension and blink rate was found, but not on the individual level, as blink rates are so variable amongst individuals. Therefore, blink rate was not deemed as a valid index for estimating muscle tension (King & Michels, 1957). Any question regarding SB rates is extremely difficult to answer without being able to directly manipulate blinks. Blink research has come a long way, but questions on the direct effects of SBs remain unanswered because there is no methodology in place to test them.

Spontaneous Blinks and Dopamine

A possible reason for blink variability is the relationship between blink rate and dopaminergic activity (Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015). The rate of spontaneous blinking is positively correlated to central dopamine activity. This can be easily seen by measuring blink rate of people with certain disorders related to dopamine (Karson, Dykman, & Paige, 1990). For example, Parkinson's, which reduces dopamine, is associated with reduced blink rates (Barbato et al., 2000). Conversely, excessive blinking is associated with schizophrenia, which increases dopamine (Karson, Dykman, & Paige, 1990; Chen & Hui, 2000). Blink rates also vary throughout the day. People blink more in the evening as dopamine levels rise (Barbato et al., 2000). The relationship between dopamine and SB rate has been well-established, and has made SB rate an accepted measure for central dopaminergic activity (Karson, 1983; Blin, Masson, Azulay, Fondarai, & Serratrice, 1990; Taylor, Elsworth, Lawrence, Sladek, Roth, & Redmond, 1999; Slagter, Georgopoulou, & Frank, 2015). Given that dopamine is closely linked to blinking, this further hints at a more complex explanation for the behavior than merely cleansing and lubricating the eye.

Although evidence supporting the relationship between dopamine and SB rate is plentiful, claims on directionality still cannot be made. It is suggested that dopaminergic activity influences SB rate, but does SB rate instead influence dopaminergic activity? This question cannot be answered until SB rate can be manipulated in order to see if and how changing it has any influence on dopamine.

However, the relationship between SB rate and dopaminergic activity alone is not enough to explain SB rate variability. While enough evidence supports the relationship that high levels of dopaminergic activity increase SB rate and low levels of dopaminergic activity decrease SB rate (Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015), it does not explain the intricate variability in the temporal patterns of SBs.

Blinking and the Brain

An increasingly popular view on spontaneous blinks is that they are timed to facilitate visual intake, and that they are linked to areas of the brain that involve higher cognitive processing (Pivik & Dykman, 2004; Rubin, Hien, Das, & Melara, 2017; Yoon, Chung, Song, & Park, 2005). It has been suggested that cognitive factors override the relationship between SB rate and dopamine during tasks (Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015). While performing cognitive tasks, blink rate is not consistent, and instead, blinks occur during optimal moments, such as before and after moments of maximum task difficulty (Drew, 1951), after making a decision, and between trials (Fukuda, 2001).

As reviewed earlier, spontaneous blinks are not only temporally related to cognition during task performance, but they may enhance cognitive performance as well (Verguts & Notebaert, 2009; Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015; van Bochove, Van der Haegen, Notebaert, & Verguts, 2013). One study found that participants who blinked more after a trial performed better on the subsequent trial than those who blinked less (van Bochove, Van der Haegen, Notebaert, & Verguts, 2013). If blinks do represent disengagement and a closure of information processing, cognitive load would slightly decrease and allot more cognitive control capacity, which would help performance on the next trial (Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015).

Implicit Mechanism for Optimal Timing

The many temporal patterns of SB rate have led many researchers to propose that there is an internal mechanism that implicitly controls the timing of blinks (Holland & Tarlow, 1975; Nakano & Kitazawa, 2010). The proposed mechanism determines the optimal time for blinking, and inhibits blinks when it would lead to the loss of critical information (Nakano & Kitazawa, 2010). This would explain why blinks tend to occur most at finishing points, such as the end of sentences, with blinks almost serving as punctuation marks (Holland & Tarlow, 1975). The gap between events (e.g., sentences, movie scenes) is the safest time to blink without the loss of important information, and this is when most blinks occur without awareness of the blinker.

The low-disruption hypothesis posits that SBs are regulated and occur during moments that are less important visually (Evinger, Shaw, Peck, Manning, & Baker, 1984). People are unaware of SBs, yet they appear to occur at optimal moments which suggests that blinking is internally regulated in a similar way to respiration and digestion. A clock-like mechanism located in the brainstem has been proposed as a possibility of how blinks are regulated (Hart, 1992), but there is not enough research to fully understand this possibility (Briggs, 1999).

Information Processing & Memory

Due to the task-dependent variability and timing of SB rate, it has been suggested that SBs may be controlled by the same mechanisms involved in information processing (Tanaka &

Yamaoka, 1993). Because blinks occur at higher rates at the end of events and when critical information is low, some researchers believe that blinks occur between periods of information processing and are inhibited during times in which visual information has to be processed (Wascher, Heppner, Möckel, Kobald, & Getzmann, 2015). Additionally, there is some evidence showing that blinks are inhibited during information processing when auditory stimuli are presented, leading researchers to infer that blinking disrupts information processing at a cognitive level and not solely in visual processing (Bauer, Strock, Goldstein, Stern, & Walrath, 1985).

While much research has supported that blinking is generally inhibited when receiving vital and relevant information and blinks tend to occur during less relevant moments, newer evidence suggests that this view is not entirely accurate. Wascher et al. (2015) demonstrated that blinks were triggered after stimulus *evaluation* was complete, not simply when stimulus presentation was complete. An extension of blink latencies after completing trials makes it plausible to infer that blinks occur once information processing is complete, which in turn leads to the hypothesis that blinks may disrupt information processing.

While many researchers broadly posit that cognitive load influences SB rate, others specifically suggest that memory plays an important role on SB rate, and there is evidence to support this. If cognitive load is kept constant, SB rate significantly decreases when a person is using working memory (Holland & Tarlow, 1975). Other researchers posit that SBs release the build-up of working memory, resulting in better inhibitory control (Hester & Garavan, 2005).

Developing a Methodology to Manipulate Spontaneous Blinks

Spontaneous blinks are, by definition, naturally occurring and non-purposeful. As such, they would appear to be almost impossible to manipulate. If a participant is instructed in any way on when to blink, the blinks are no longer spontaneous. Thus, any information acquired from these types of studies is about voluntary blinks. In order to move away from correlational studies and gain knowledge on the direct effects of spontaneous blinks, an experimental method that naturally manipulates spontaneous blinks must be created and validated.

Research has shown that SBs are dynamic, and that many factors can change blink frequency. As previously mentioned, people blink at higher frequencies when they are engaged in a social conversation, and at lower frequencies when reading a book. People also blink less during a high intensity scene during a movie as opposed to a boring landscape scene. Based on these findings, it may be possible to develop a method in which spontaneous blink rate can be manipulated without participant awareness. This method would make it possible to experimentally test hypotheses about spontaneous blinks without accidentally measuring voluntary blink rates.

Based on the previously reviewed body of research, it is hypothesized that watching videos of a speaker's face will manipulate blink rate. Specifically, it is predicted that participants watching a video of a speaker with a low blink rate will lower participant blink rate. Conversely, watching a video of the speaker with a high blink rate will increase participant blink rate. It is also hypothesized that participants will imitate the speaker's blink timing and blink immediately after the speaker blinks, called blink entrainment (Nakano & Kitazawa, 2010).

Method

Participants

Twenty-six volunteers were recruited from a Midwestern university to participate in this study for class credit. Five ($F = 5$) of the 26 volunteers participated in the pilot study as described below, and 21 participated in the experiment. The data of two participants were excluded from analysis due to frequent eye movements away from the computer screen, leaving a total of 19 participants. Participants were required to have good vision or use contact lenses. Participant age (*M* = 23.84, *SD* = 5.10, Range = 18-38) was obtained to rule out possible confounds. Participants were mostly female (*F* = 16, *M* = 3), and all participants were native English speakers.

Materials

Participants completed the study on Dell Optiplex 380 computers with Dell 1708FP (1280 x 1024) flat panel monitors. Blink rate was measured with the SMI SensoMotoric Eye-tracking ETG unit, which records eye movements at 30 hz and also measures eye-blinks. Six different video clips were created using CrazyTalk 8.0 animation software. Each video clip featured the animated face of a woman speaking directly to the participant about how to complete each portion of the experiment. These video clips appeared to simply be experiment instructions, but were in fact the experiment stimuli. Each video was 50 seconds long and contained the same number of sentences and a similar word count. The voice of the speaker was narrated by a human woman to make the animation feel as real as possible. In half of the videos, the speaker displayed a low blink frequency and in the other half a high blink frequency. The order of blink frequency was counterbalanced among participants. Although participants were shown six videos featuring the speaker, only the four videos explaining task instructions were used for analysis. The first video was a greeting and the last video was a debriefing. These allowed participants to acclimate and transition into and out of the experiment, thereby avoiding confounds.

Between watching the speaker videos, participants completed several variations of a lexical word task. The lists of words and non-words were obtained from the English Lexicon

Project website. The experiment was designed with Ogama – Gaze and Mouse Analyzer 5.0 software. Participants completed the study in one of five small (8 x 10ft.), quiet laboratory rooms. The rooms were lit with fluorescent bulbs, and were the same intensity in every room to control for possible light-related confounds. Eye-movements were recorded with the SMI SensoMotoric Eye-tracking and ETG glasses unit, along with the software iViewETG 2.7 and BeGaze 3.7.

Pilot Study

A small pilot study was conducted prior to the experiment to examine if blink rates differed while watching an animated speaker as opposed to a human speaker. The goal of this study was to develop a standardized methodology to manipulate blink rates. In order to do this, an animated speaker was created instead of using a human. Using an animated speaker has the advantage of complete control of facial expression, blink duration, and timing, all of which are necessary for standardization.

For the pilot, five participants watched two videos of a speaker talking about clinical psychology while wearing eye-tracking technology. One of the videos featured the face of a human woman speaker, while the other featured a computer-generated, animated speaker. In a counterbalanced order to ensure validity, all participants viewed both three-minute videos. The animated speaker's blinks were programmed to match the blinks of the human speaker, to ensure that the animation was the only difference between the two videos. The audio for the animated speaker was taken from an unheard portion of the human speaker video. This provided the same voice for both speakers, and continuity of the topic discussed. The videos were counterbalanced to ensure validity. A Wilcoxon signed-rank test showed that participant blink rates while watching the human speaker (M = 90.6, SD = 11.72) and the animated speaker (M = 83.4, SD=

10.55) did not reliably differ ($Z = -1.08$, $p = .279$). This allowed for the use of an animated model for the primary experiment of the study.

Procedure

After being greeted and given a consent form to sign, participants were seated and calibrated to the eye-tracker. They were told that their eye-movements would be tracked, but nothing about blinking was mentioned. Participants were given headphones and told that they would receive instructions to complete several tasks on the computer. Once they were in a comfortable position and with their fingers on the keyboard, they began the experiment. In the first video, the speaker greeted the participant and generally explained what they would be doing. The tasks were variations of a lexical decision task. Participants were instructed to make different decisions about words and non-words (see Figure 1 for task instructions). The tasks ensured that participants remained engaged, and the different variations provided the reason for having four very similar videos of instructions. After each video (excluding video 1 and video 6), participants completed ten trials of the task. Once they completed the last task, they were shown the last video of the speaker debriefing them and concluding the experiment. All participants completed the experiment before two in the afternoon to avoid spontaneous blink variability attributed to time of day.

A within-participant design was used to test whether the independent variable, speaker blink rate (high vs. low), would alter the dependent variables, participant blink frequency and blink entrainment. In this experiment, participant blink rate is defined as the number of blinks during each video, and blinking within two seconds after the speaker is referred to as blink entrainment. Half of the videos seen by participants were programmed so that the speaker had a high blink rate (22 blinks), and the other half were programmed to a low blink rate (8 blinks).

The values for blink rate were chosen because they were far enough from the mean blink rate (15 blinks per minute), yet still seemed natural when watching the speaker.

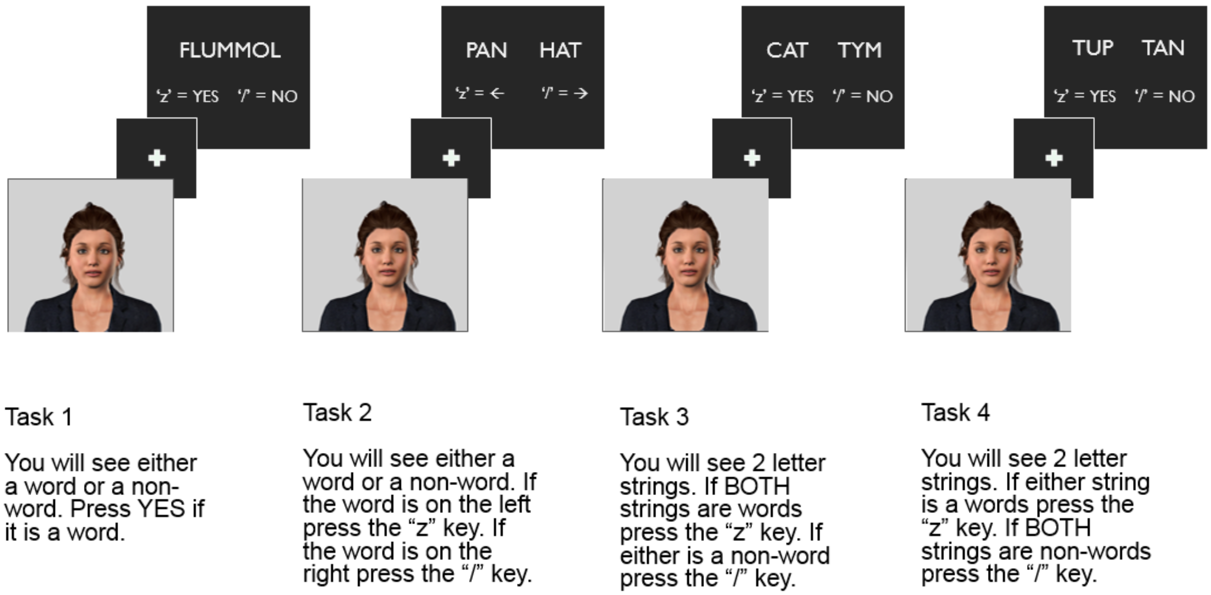

Figure 1. Example stimuli slides for each relevant block of the experiment. Each block began with a video of the animated speaker providing instructions for the task. Each block contained 10 trials of the task.

Data Analysis

Participant eye movements and events were recorded with the SMI SensoMotoric Eye-tracking ETG unit. In addition to recording eye movements and events, the SMI eye-tracker records scene video, producing a timestamped video of what the participant was looking at during the experiment. Using the accompanying unit software, BeGaze 3.7, areas of interest were placed on each participant's scene recording. This was done to ensure that participants were watching the speaker during a blink event. Two participants were excluded from analysis due to frequent eye movements outside the area of interest.

The SMI eye-tracking unit does not differentiate between true blinks and a loss of participant gaze. Both events are categorized as "blinks". In order to determine true blink events, the raw data files containing all eye events were examined to determine blink time and duration for each participant. Any event categorized as a blink lasting longer than 550ms was discarded, as true blink events typically lasted from 100ms to 400ms. A loss of participant gaze also resulted in missing data for several other events, whereas true blinks only lost pupil data for a short duration. Additionally, a true blink was only considered for analysis if eye gaze was in the area of interest during the blink event. To determine if blink rate was manipulated by speaker blink rate, participant blink frequency during the high blink rate videos was compared to blink frequency during the low blink rate videos. To test the blink entrainment hypothesis, blink times were compared to speaker blink times across the four videos. Based on past research findings, if a participant blink occurred during or up to two seconds after the onset of a speaker blink, it was considered blink entrainment.

A time window of about one second is commonly used because elicited eye blinks do not occur at the exact moment of the stimulus onset and thus a short time lag is required to detect temporal relationships (Bonneh, Adini, & Polat, 2016; Nakano & Kitazawa, 2010). However, new research shows that when dealing with non-human stimuli, entrainment can occur after the one second window (Tatsukawa, Nakano, Ishiguro, & Yoshikawa, 2016). Therefore, a lag time of two seconds was chosen to ensure that any behavioral patterns were detected.

Eye tracking data is complex and extremely variable, and therefore often fails to meet the assumptions of parametric tests. The data for this experiment fails to meet the assumption of normality, as it does not distribute evenly. The data from all conditions was dependent on other samples because participants completed both experimental conditions. Therefore, the non-parametric equivalent of a paired-samples t-test, the Wilcoxon signed-rank test, was used to analyze the data.

Results

Eye-tracking data was analyzed to determine whether participants displayed higher blink rates while watching the videos in which the speaker had a high blink frequency, and lower blink rates while watching videos in which the speaker had a low blink rate. As expected, the data did not distribute normally, so non-parametric tests were used to analyze the data. A Wilcoxon signed-rank test showed that the differences between participant blink rates across the high blink rate and the low blink rate were significant (Z = -3.16, p = .002). Participants blinked more frequently while watching the high blink rate videos than when watching the low blink rate videos (see Figure 2).

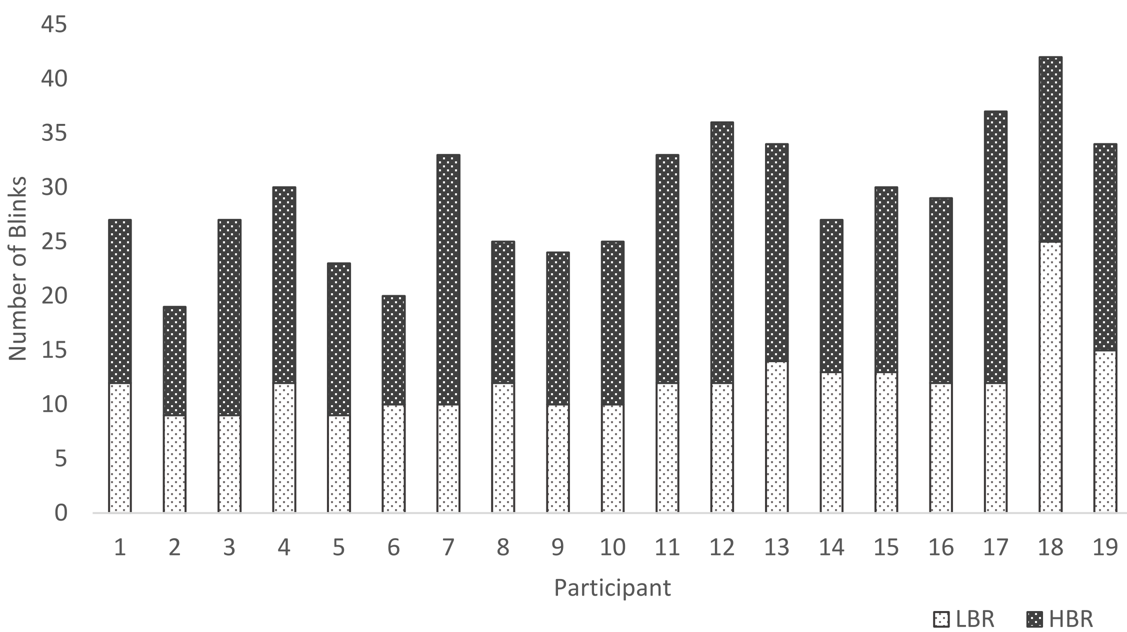

Figure 2. Number of participant blinks while watching the high blink rate (HBR) videos and low blink rate (LBR) videos.

Participant data was analyzed to determine whether there was a temporal relationship between speaker and participant blinks, with participant blinks following closely after speaker blinks. A Wilcoxon signed-rank test showed a significant difference between entrainment blinks and non-entrainment blinks in the high blink rate condition ($Z = -3.65$, $p = .001$), and the low blink rate condition ($Z = -2.21$, $p = .027$). These results show reliable blink patterns exhibited by participants in both conditions in which they participated (see Figure 3).

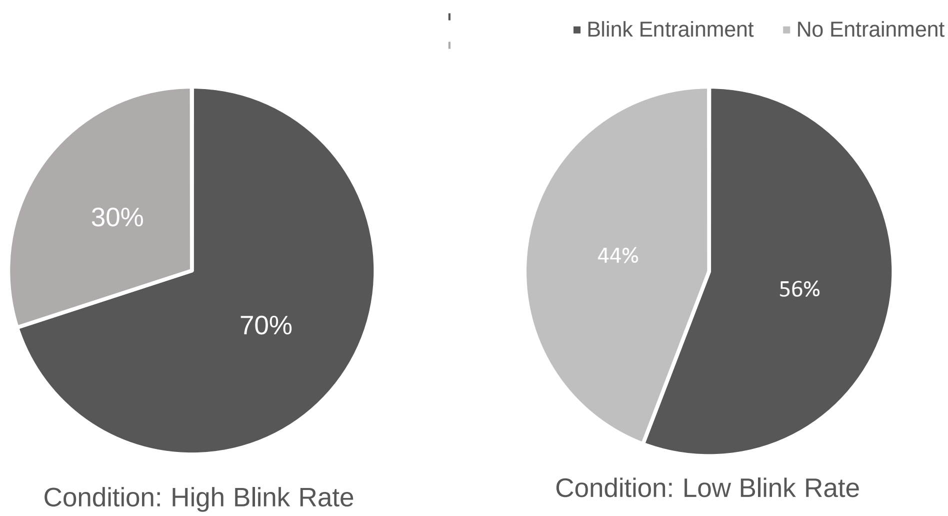

Figure 3. Average percentage of participant entrainment blinks while watching the high blink rate (HBR) videos and low blink rate (LBR) videos.

Discussion

The aim of this study was to determine whether spontaneous blink rate could be manipulated by watching videos of an animated speaker. One way to determine this was to examine whether participant blink rate changed as a result of speaker blink rate. It was hypothesized that participants would display higher blink rates while watching the videos in which the speaker had a high blink frequency, and lower blink rates while watching videos in which the speaker had a low blink rate. As expected, participants showed reliably higher blink rates while watching the high blink rate videos than when watching the low blink rate videos.

The experiment required high levels of attention in order to complete each task successfully. Participants had lower blink rates in general than typically seen in people who are not highly focused. Lower blink rates during tasks that require high attention is a relationship that has been consistently found in the literature, so this was expected (Stern, Boyer, & Schroeder, 1994). Despite the higher levels of attention, participant blink rate during the high blink rate videos increased, suggesting that perhaps social aspects of spontaneous blinks override attentional aspects If social components can override attentional processes, spontaneous blinks likely play a crucial role in communication and other social functions.

The second hypothesis, that participant blinks would become entrained to speaker blinks with a lag of two seconds was also supported. Participant blinks occurred mostly after a speaker blink, an effect present during both high blink rate and low blink rate speaker videos. Blink entrainment has been observed in other studies (Nakano & Kitazawa, 2010; Dahlin, Bach, & Phillips, 2013), yet it has never been observed while using a computer-generated animated speaker. The fact that the same effect occurs with the use of animated speakers affords method standardization possibilities and opens the door for new studies and exact experiment replications.

The results of this study show that the dynamic nature of spontaneous blinks makes it possible to develop methods to manipulate them in either direction. Spontaneous blinks have been closely tied to two major areas: social aspects (Nakano, Kato, & Kitazawa, 2011; Tada, Omori, Hirokawa, Ohira, & Tomonaga, 2013) and cognitive processes (Stern, Boyer, &

Schroeder, 1994; Sheline et. al, 2009). These relationships can be used to manipulate spontaneous blinks, as the present study shows.

Spontaneous blinks show great variability during social communication. As previously mentioned, blink rate increases when engaged in a conversation. Additionally, people tend to mimic each other's blinks when conversing. Higher blink rates also occur at the end of sentences and breakpoints in speech. The participants in this study responded to speaker blink frequency, and speaker blink timing, suggesting that any number of these social aspects can be manipulated using computer-generated animated speakers.

The influences of cognitive aspects were also seen during this experiment. Participants had lower than average blink rates throughout the experiment, most likely due to the high levels of attention required to complete each task. Additionally, participant blink rate decreased while completing each block of the lexical decision task. It cannot be inferred from blink rate alone that the lexical decision task required more attention than the speaker videos, as tasks requiring higher visual processing appear to have a stronger influence on blink rate. It would be valuable to experimentally determine whether higher visual processing does indeed lead to lower blink rates. Now that the first step towards developing a methodology for manipulating spontaneous blinks has been taken, these types of questions can begin to be answered.

The findings of this study provide many new possibilities for examining spontaneous blink rates. Although more research is needed to determine the strength and validity of these methods, they provide a starting point for examining the effects of experimentally induced spontaneous blinks.

In addition to eye-tracking data, response time and accuracy data were recorded for each participant. These data were not usable until the question of whether spontaneous blinks were successfully manipulated or not was answered. Now that the results of this experiment have shown the effectiveness of manipulating spontaneous blinks and causality can be inferred, new questions can be answered. For example, did blink rate influence response times and accuracy on the lexical decision tasks?

Several limitations were present in this study that should be considered in future research. Although eye-tracking studies tend to have smaller populations, larger sample sizes would produce more generalizable results, especially with something as variable as blink rate. Additionally, the task-type completed by the participants likely lowered their average blink rate due to the amount of attention they had to allocate to each block. It is likely that a larger difference between the high and low blink rate videos would be found if participants were not as focused on how to complete each task.

Future research should first focus on validating this method and developing an optimal methodology for manipulating spontaneous blinks if necessary. Future research would further benefit from experimenting with different versions of animated speakers. The speaker had to remain exactly the same for the hypotheses examined in this study, but altering speaker movements, facial gestures, and/or voice could have a large influence on participant blink behavior. Additionally, more research on task type would be beneficial to determine how much of an influence the task itself had on participant blink rates. Perhaps a stronger effect would be found if the task did not require as much focus. Conversely, a task requiring less attention could decrease the effect, as blink rate tends to increase when people are not paying attention. This would make it difficult to determine whether any effect found was due to participants paying attention to the speaker videos. Further research should focus on these details in order to add to the current information on developing an optimal methodology for manipulating spontaneous blinks.

Spontaneous blinks are infrequently studied, and when they are, they often use quasi-independent sorting due to a lack of valid manipulation methods. People with naturally higher blink rates are placed in one condition and people with lower blink rates in another. This method is a great first step to exploring spontaneous blinks, but wide generalizations cannot be made. The only way to learn the effects of spontaneous blinks is to be able to experimentally manipulate them. The animated speaker videos in this study were able to alter participant blink rates, along with the timing of a significant amount of participant blinks. With the use of the animated speaker videos, spontaneous blinks can begin to be manipulated. More research testing these tools and variations of them is needed in order to advance the current state of knowledge on spontaneous blinking. The variability that exists in spontaneous blinks is there for a reason. Investigating them through manipulation is the only way to get answers to the mystery of these blinks.

References

Agostino, R., Bologna, M., Dinapoli, L., Gregori, B., Fabbrini, G., Accornero, N., & Berardelli, A. (2008). Voluntary, spontaneous, and reflex blinking in Parkinson's disease. *Movement Disorders*, *23*(5), 669-675.

Barbato, G., Ficca, G., Muscettola, G., Fichele, M., Beatrice, M., & Rinaldi, F. (2000). Diurnal variation in spontaneous eye-blink rate. *Psychiatry Research*, *93*(2), 45-51.

Bauer, L. O., Strock, B. D., Goldstein, R., Stern, J. A., & Walrath, L. C. (1985). Auditory discrimination and the eyeblink. *Psychophysiology*, *22*(6), 636-641.

Baumstimler, Y., & Parrot, J. (1971). Stimulus generalization and spontaneous blinking in man involved in a voluntary activity. *Journal of Experimental Psychology*, *88*(1), 95.

Blin, O., Masson, G., Azulay, J. P., Fondarai, J., & Serratrice, G. (1990). Apomorphine-induced blinking and yawning in healthy volunteers. *British Journal of Clinical Pharmacology*, *30*(5), 769-773.

Bonneh, Y. S., Adini, Y., & Polat, U. (2016). Contrast sensitivity revealed by spontaneous eyeblinks: Evidence for a common mechanism of oculomotor inhibition. *Journal of Vision, 16*, 1–15

Briggs, S. T. (1999). Spontaneous blink rate of a normal population sample. *International Contact Lens Clinic, 26*(2), 29-32.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network. *Annals of the New York Academy of Sciences*, *1124*(1), 1-38.

Chen, E. Y. H., & Hui, C. W. S. (2000). Spontaneous blink rate in first-episode schizophrenic patients: A prospective follow-up study. *Schizophrenia Research*, *41*(1), 263-264.

Dahlin, J., Bach, E., & Phillips, F. (2013). Blink inhibition and entrainment. *Journal of Vision*, *13*(9), 433-433.

De Gelder, B. (2006). Towards the neurobiology of emotional body language. *Nature Reviews Neuroscience*, *7*(3), 242-249.

Deuschl, G., & Goddemeier, C. (1998). Spontaneous and reflex activity of facial muscles in dystonia, Parkinson's disease, and in normal subjects. *Journal of Neurology, Neurosurgery & Psychiatry*, *64*(3), 320-324.

Drew, G. C. (1951). Variations in reflex blink-rate during visual-motor tasks. *Quarterly Journal of Experimental Psychology*, *3*(2), 73-88.

Evinger, C. (1995). A brain stem reflex in the blink of an eye. *Physiology*, *10*(4), 147-153.

Evinger, C., Shaw, M. D., Peck, C. K., Manning, K. A., & Baker, R. (1984). Blinking and associated eye movements in humans, guinea pigs, and rabbits. *Journal of Neurophysiology*, *52*(2), 323-339.

Fukuda, K. (2001). Eye blinks: new indices for the detection of deception. *International Journal of Psychophysiology*, *40*(3), 239-245.

Goldstein, R., Walrath, L. C., Stern, J. A., & Strock, B. D. (1985). Blink activity in a discrimination task as a function of stimulus modality and schedule of presentation. *Psychophysiology*, *22*(6), 629-635.

Guipponi, O., Odouard, S., Pinède, S., Wardak, C., & Hamed, S. B. (2014). fMRI cortical correlates of spontaneous eye blinks in the nonhuman primate. *Cerebral Cortex*, bhu038.

Hall, A. (1945). The origin and purposes of blinking. *The British Journal of Ophthalmology*, *29*(9), 445.

Hester, R., & Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. *Memory & Cognition*, *33*(2), 221-233.

Holland, M. K., & Tarlow, G. (1975). Blinking and thinking. *Perceptual and Motor Skills*, *41*(2), 403-406.

Iacoboni, M. (2009). Imitation, empathy, and mirror neurons. *Annual Review of Psychology*, *60*, 653-670.

Karson, C. N. (1983). Spontaneous eye-blink rates and dopaminergic systems. *Brain*, *106*(3), 643-653.

Karson, C. N., Dykman, R. A., & Paige, S. R. (1990). Blink rates in schizophrenia. *Schizophrenia Bulletin*, *16*(2), 345.

Karson, C. N., Lewitt, P. A., Calne, D. B., & Wyatt, R. J. (1982). Blink rates in parkinsonism. *Annals of Neurology*, *12*(6), 580-583.

Kato, M., & Miyauchi, S. (2003). Functional MRI of brain activation evoked by intentional eye blinking. *Neuroimage*, *18*(3), 749-759.

King, D. C., & Michels, K. M. (1957). Muscular tension and the human blink rate. *Journal of Experimental Psychology*, *53*(2), 113.

Kugiumutzakis, G. (1996). Le développement de l'imitation précoce de modèles faciaux et vocaux. *Enfance*, *49*(1), 21-25.

Matsuno, S., Ohyama, M., Ohi, S., Abe, K., & Sato, H. (2013). Automatic discrimination of voluntary and spontaneous Eyeblinks: The use of the blink as a switch interface.

Meier, B., & Zimmermann, T. D. (2015). Loads and loads and loads: The influence of prospective load, retrospective load, and ongoing task load in prospective memory. *Frontiers in Human Neuroscience, 9*.

Meyer, D. R. On the interaction of simultaneous responses. *PsychoL Bull.*, 1953, SO, 204-220.

Nakano, T., Kato, N., & Kitazawa, S. (2011). Lack of eyeblink entrainments in autism spectrum disorders. *Neuropsychologia*, *49*(9), 2784-2790.

Nakano, T., Kato, M., Morito, Y., Itoi, S., & Kitazawa, S. (2013). Blink-related momentary activation of the default mode network while viewing videos. *Proceedings of the National Academy of Sciences*, *110*(2), 702-706.

Nakano, T., & Kitazawa, S. (2010). Eyeblink entrainment at breakpoints of speech. *Experimental Brain Research*, *205*(4), 577-581.

Nakano, T., Yamamoto, Y., Kitajo, K., Takahashi, T., & Kitazawa, S. (2009). Synchronization of spontaneous eyeblinks while viewing video stories. Biological Sciences, DOl: 10.1 098/rspb.2009.0828

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology:Ggeneral*, *130*(3), 466.

Orchard, L. N., & Stern, J. A. (1991). Blinks as an index of cognitive activity during reading. *Integrative Physiological and Behavioral Science*, *26*(2), 108-116.

Pivik, R. T., & Dykman, R. A. (2004). Endogenous eye blinks in preadolescents: Relationship to information processing and performance. *Biological Psychology*, *66*(3), 191-219.

Ponder, E., & Kennedy, W. P. (1927). On the act of blinking. *Quarterly Journal of Experimental Physiology*, *18*(2), 89-110.

Ricciardelli, P., Bricolo, E., Aglioti, S. M., & Chelazzi, L. (2002). My eyes want to look where your eyes are looking: Exploring the tendency to imitate another individual's gaze. *Neuroreport, 13*(17), 2259-2264.

Rubin, M., Hien, D. A., Das, D., & Melara, R. D. (2017). Inhibitory control under threat: The role of spontaneous eye blinks in post-traumatic stress disorder. *Brain Sciences, 7*(2), 16.

Senju, A., & Johnson, M. H. (2009). Atypical eye contact in autism: Models, mechanisms and development. *Neuroscience & Biobehavioral Reviews, 33*(8), 1204-1214.

Sheline, Y. I., Barch, D. M., Price, J. L., Rundle, M. M., Vaishnavi, S. N., Snyder, A. Z., Mintun, M.A., Wang, S., Coalson, R. S., & Raichle, M. E. (2009). The default mode network and self-referential processes in depression. *Proceedings of the National Academy of Sciences,106*(6), 1942-1947.

Shen, X. B., Wu, Q., & Fu, X. L. (2012). Effects of the duration of expressions on the recognition of microexpressions. *Journal of Zhejiang University Science B*, *13*(3), 221-230.

Slagter, H. A., Georgopoulou, K., & Frank, M. J. (2015). Spontaneous eye blink rate predicts learning from negative, but not positive, outcomes. *Neuropsychologia, 71*, 126-132.

Stel, M., & Vonk, R. (2010). Mimicry in social interaction: Benefits for mimickers, mimickees, and their interaction. *British Journal of Psychology*, *101*(2), 311-323.

Stern, J. A., Boyer, D., & Schroeder, D. (1994). Blink rate: A possible measure of fatigue. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *36*(2), 285-297.

Stern, J. A., Walrath, L. C., & Goldstein, R. (1984). The endogenous eyeblink. *Psychophysiology*, *21*(1), 22-33.

Tanaka, Y., & Yamaoka, K. (1993). Blink activity and task difficulty. *Perceptual and Motor Skills*, *77*(1), 55-66.

Tatsukawa, K., Nakano, T., Ishiguro, H., & Yoshikawa, Y. (2016). Eyeblink synchrony in multimodal human-android interaction. *Scientific Reports*, *6*, 397-418.

Taylor, J. R., Elsworth, J. D., Lawrence, M. S., Sladek, J. R., Roth, R. H., & Redmond, D. E. (1999). Spontaneous blink rates correlate with dopamine levels in the caudate nucleus of MPTP-treated monkeys. *Experimental neurology*, *158*(1), 214-220.

Trivers, R. L. (1971). The evolution of reciprocal altruism. *The Quarterly Review of Biology*, *46*(1), 35-57.

Tsubota, K., Kwong, K. K., Lee, T.Y., Nakamura, J., & Cheng, H. M. (1999). Functional MRI of brain activation by eye blinking. *Experimental Eye Research*, 69(1), 1-7.

van Bochove, M. E., Van der Haegen, L., Notebaert, W., & Verguts, T. (2013). Blinking predicts enhanced cognitive control. *Cognitive, Affective, & Behavioral Neuroscience*, *13*(2), 346-354.

VanderWerf, F., Brassinga, P., Reits, D., Aramideh, M., & de Visser, B. O. (2003). Eyelid movements: behavioral studies of blinking in humans under different stimulus conditions. *Journal of Neurophysiology*, *89*(5), 2784-2796.

Verguts, T., & Notebaert, W. (2009). Adaptation by binding: a learning account of cognitive control. *Trends in Cognitive Sciences*, *13*(6), 252-257.

Volkmann, F. C., Riggs, L. A., Ellicott, A. G., & Moore, R. K. (1982). Measurements of visual suppression during opening, closing and blinking of the eyes. *Vision Research, 22*(8), 991-996.

Vrij, A. (2000). Detecting lies and deceit: The psychology of lying and implications for professional practice.

Vrij, A., & Mann, S. (2001). Who killed my relative? Police officers' ability to detect real-life high-stake lies. *Psychology, Crime and Law*, *7*(1-4), 119-132.

Ward, J. (2005). Physiology of breathing I. *Surgery (Oxford)*, *23*(11), 419-424.

Wascher, E., Heppner, H., Möckel, T., Kobald, S. O., & Getzmann, S. (2015). Eye-blinks in choice response tasks uncover hidden aspects of information processing. EXCLI journal, 14, 1207.

Yoon, H. W., Chung, J. Y., Song, M. S., & Park, H. (2005). Neural correlates of eye blinking; improved by simultaneous fMRI and EOG measurement. *Neuroscience Letters*, *381*(1), 26-30.