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The Startle Eyeblink Response

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The purpose of this chapter is to describe the various methodological issues that researchers should consider when using the startle response as a way to investigate personality and social psychology. Although this chapter is not a review of variations in startle as a function of personality and social psychological factors, it does provide a summary and assessment of the methods used in these areas. Understanding these methods not only will be useful when investigators are deciding how to utilize startle as a measure, but also will be vital to interpreting the findings in this area. Even though the purpose of this chapter is not to persuade readers to add startle to their own research programs, it is our hope that the methods and ideas reviewed here will facilitate the effective application of startle to the study of problems and processes that have not traditionally been examined with startle. Readers may wish to use startle in their own research for any of several reasons: (1) Startle is sensitive to many things and can therefore be used as a measure of those things; (2) the anatomy and chemistry underlying startle have been largely identified, due to the fact that this response is available across many animal species—a fact that supports both translational research and a more complete understanding of the mechanisms underlying those things that startle measures; and (3) startle is relatively easy to measure, and the data are relatively easy to reduce into an understandable form.

With that said, we remind our readers that the intention of this chapter is to make their use of startle more informed and dynamic.

What Is Startle, and Why Use It?

Defensive Activation

Startle is considered to be a defensive response, with skeletal muscle activity serving to protect the back of the neck, facial muscle activity serving to protect the eyes, and increased sympathetic nervous system activity serving to ready the organism for further action (Yeomans, Li, Scott, & Frankland, 2002). The startle response generally functions either to protect the organism from bodily harm or to propel the organism from a situation in which such harm may occur. This defensive startle response may be viewed as an index of the organism's ability to respond to danger, and can be expected to increase in situations in which danger (either real or perceived) is more likely. This makes startle a useful measure of relatively automatic reactivity to such situations, with this reactivity expected to vary as social and personality characteristics differ.

With variations in methodology, the startle response can be utilized to index a variety of neurocognitive processes, including arousal, emotion, attention, and information processing. Likewise, depending on the specific methods used, the startle response can also be employed to index neurological functioning in various areas, including the brainstem, limbic system, and frontostriatal areas. It should be noted that the specificity and reliability of the startle response as a measure of these processes and functions is strongly tied to the type and quality of the methods utilized.

Advantages and Disadvantages of Startle

Ironically, the primary disadvantage of startle as a measure is also its primary advantage: the fact that it is so sensitive to so many things. This sensitivity allows us to use startle in a wide variety of experimental situations to investigate an equally wide variety of research questions. However, this sensitivity also requires us to control extraneous factors that could add error or confusion to our results. In order to reliably and validly measure specific factors of interest, we must be mindful of our specific methods and their ability to control or eliminate as many of these extraneous factors as possible. Alternatively, these extraneous factors may actually be used in the design of new experiments, becoming independent or classification variables. The error in one study may be the effect in another.

Relative to many other neurobiological measures, startle has a short and precise onset latency. The eyeblink component of the startle response has a latency of approximately 50 msec, which means that the blink has already occurred by the time a person is consciously aware that a stimulus has been presented. Consequently, a researcher can be confident that the blink is a response to the eliciting stimulus (although spontaneous eyeblinks fall inside the scoring window for reflex blinks on 1–3% of trials). This allows the researcher to monitor the participant and withhold the startle stimulus until the participant is sitting still, for example. This also allows the blink to be elicited at a specific time, such as following a change in the social environment, or 0.5 sec after some other stimulus has been presented.

Startle also has the advantage of being available across the lifespan, in that it can be measured in the same manner in infants, adolescents, younger adults, and older adults. This allows one to look at developmental progressions of the factor of interest with a measurement methodology (eyeblink electromyography [EMG]) that is consistent across ages. For example, with the paradigm involving prepulse inhibition of startle, it may be possible to evaluate the developmental course of frontostriatal functioning in introverted versus extraverted personalities, or to examine the impact of social stressors on this developmental course. A related advantage is the fact that startle can be elicited from participants when they are either awake or asleep, making it a useful measure in neonatal research (Blumenthal, Avendano, & Berg, 1987).

Just as startle is available across the lifespan, it is also measurable across much of the phylogenetic spectrum, allowing for the application of startle in the investigation of animal models of human conditions and processes. Analogous responses, and in some cases the same responses, can be used to investigate the mechanisms underlying factors across species. The startle response and its underlying neuroanatomy are relatively simple (Davis, 2006); however, the fact that the startle pathway receives input from, and projects to, a number of other locations in the central nervous system makes this response useful in evaluating activity in a variety of other systems. For example, startle can be used to measure activation of the amygdala, the frontal cortex, various sensory systems, the tegmentum, and many other locations (Swerdlow, Geyer, & Braff, 2001). This allows us to use startle to quantify emotion, arousal, attention, perceptual sensitivity, and many other factors, including personality and social psychological factors.

Like many other psychophysiological measures, startle is more automatic than self-report measures; consequently, it has the advantage of being able to provide information that is less likely to be tainted by response bias. For example, the magnitude of the startle response is

larger when state anxiety is greater (Grillon, 2002), and this may be true even if the participant from whom startle is being measured is not aware of that increased anxiety (Grillon & Davis, 1997). The point here is that startle may be more sensitive than some self-report measures are to variations that are below the level of awareness. In this way, startle may be a useful way to access variables related to personality and social functioning that may be unavailable to or obscured by other methods.

Measuring the Startle Response

Overview

Startle can be affected by three categories of factors: (1) situational factors external to the participant, such as stimulus parameters or contextual cues; (2) characteristics of the participant, such as clinical diagnosis, the presence of drugs, conditioning history, or social and personality traits; and (3) information-processing methods by which the participant takes in and integrates information from the environment, such as attention, emotion, and arousal. A great deal of overlap and interaction occurs among these three categories, and, accordingly, to the extent that certain variables are controlled or manipulated, researchers may examine these factors as either independent or interactive factors. For instance, emotional modulation of startle may vary as a function of personality characteristics (Patrick, Bradley, & Lang, 1993); these personality characteristics may interact with environmental stimuli (Grillon & Baas, 2003); and stimulus parameters may interact with all of these (Britt & Blumenthal, 1992). These relationships can also depend on how the situation is perceived (Flaten & Blumenthal, 1999; Haerich, 1994). Although it may seem as if this intertwining of factors would make any research outcome uninterpretable, the fact that startle is sensitive to all of these factors means that we can use startle to tease apart these interrelated issues. However, this requires experimentally stabilizing as many factors as possible, in order to allow variations in startle reactivity to reflect variations in the single factor of interest. Startle is not unique in this respect; isolating the variable of interest is necessary in any research design whenever the dependent variable can be affected by more than one factor. Such methodological control increases the extent to which results can be compared across studies, following the minimization of confounds. Whereas more methodological rigor may limit the degree to which results can be generalized to other situations, this rigor is necessary for internal validity. This issue is somewhat more important in startle research than in some other paradigms, due to the exquisite sen-

sitivity of startle to a variety of influences (Blumenthal et al., 2005). Accordingly, for the sake of interpretability of results, it is essential that methodological decisions be scrupulously reported.

Specific Methodology

Basic Methods

The startle response in humans consists of several components, including skeletal muscle activity, facial muscle activity, changes in heart rate and skin conductance, and cortical evoked potentials (Berg & Balaban, 1999). In humans, the eyeblink component of the startle response is the component most often recorded because it is easy to measure, exceedingly sensitive to a wide variety of parameters, and the earliest and most habituation-resistant component of the startle response. Correspondingly, measuring eyeblinks allows startle to be reliably measured, even after over 100 trials (Blumenthal et al., 2005). The startle eyeblink reflex is quantified by recordings of the electrical activity (EMG) of the facial muscle that closes the eyelid, the orbicularis oculi (Blumenthal et al., 2005). This muscle activity, recorded from electrodes taped to the surface of the skin (see Figure 6.1), provides a measure of the output of the facial motor nucleus in the brainstem, allowing for a relatively noninvasive measure of central nervous system activity. The facial motor nucleus is activated by the startle center—the nucleus reticularis pontis caudalis, located in the pons (Lee, Lopez, Meloni, & Davis, 1996). This startle center receives input from many structures, and projects to a variety of response-activating locations. The facts that the startle response is similar across species, and that these anatomical pathways are similar across species, mean that we can use the startle response in translational research to identify the physiological mechanisms underlying those factors resulting in differences in startle reactivity. For example, a great deal has been learned about the physiology of anxiety in humans by studying fear-potentiated startle in rats (Davis, 2006).

FIGURE 6.1. Placement of EMG recording electrodes. Photo by Ken Bennett.

One important consideration in evaluating startle eyeblink responses is the fact that there is a wide range of baseline startle reactivity across participants (Blumenthal, Elden, & Flaten, 2004). It is not unusual for the most reactive participant in a study to have average baseline startle responses 50 times larger than those of the least reactive individual. This means that comparing startle reactivity across individuals without compensating for these variations in baseline startle magnitudes may be misleading. Fortunately, there are several ways to deal with this problem (see Blumenthal et al., 2004). For example, a researcher may convert startle magnitudes to standard scores, either within an individual or across individuals within a group. Of course, this should not be done across groups if a group effect is the actual research question under study. Alternatively, a few preliminary trials may be presented in order to determine the baseline reactivity of each participant, with subsequent reactivity in the various experimental conditions then being a ratio of that initial baseline reactivity. If premanipulation baseline trials are used, the researcher must consider the fact that startle normally habituates, so one of the experimental conditions should involve an absence of the factor under study. For example, if the experiment calls for comparing two levels of a variable within participants, the study would have four blocks of trials: a first block of startle-alone trials, followed by three test trial blocks (one with each level of the variable in question, and one block with just startle stimuli again). If the order in which conditions are presented is counterbalanced, then the block of startle-alone trials can be used to index the extent of habituation, and this can then be used to more accurately evaluate the impact of the actual experimental variables.

Methodological considerations for determining the way in which eyeblink EMG is used to quantify the startle response are explained in detail by Blumenthal and colleagues (2005). Briefly, two recording electrodes are attached to the face below the eye, with a ground electrode placed elsewhere (often on the temple or the forehead), and the EMG activity of the orbicularis oculi muscle is recorded for a specified period of time following the presentation of an eliciting stimulus. That EMG activity is then processed in specific ways (see Blumenthal et al., 2005) to extract such response parameters as magnitude, amplitude, onset latency, and probability. These can then be analyzed across the factors of experimental interest (e.g., stimulus intensity, personality classification, experimental condition). Hess (Chapter 5, this volume) also discusses EMG signal processing.

Importance of Experimental Control

A researcher must also be careful to control as many parameters of the testing situation as possible, because startle is so exquisitely sensitive to so many things. For example, an increase in startle may occur because of attention being directed toward the modality in which the startle stimulus is presented (Neumann, Lipp, & McHugh, 2004), because of an increase in general arousal (Dillon & LaBar, 2005), or because of an increase in negative affect (Vrana, Spence, & Lang, 1988). If the parameter under investigation is emotional modulation of startle, then failing to control for attention and arousal may yield misleading results. In fact, in emotional-modulation-of-startle studies, pleasant and unpleasant slides both result in an increase in arousal, although they have opposite effects on startle reactivity if the inherent arousal level of the slide is sufficiently high (Cuthbert, Bradley, & Lang, 1996). For example, startle sessions are often boring for the participant, so variations in arousal can be minimized by keeping the session as short as possible, by asking the participant to sit still, and by avoiding such instructions as "Relax" or "Don't blink." Attentional variability can be minimized by removing interesting and potentially distracting objects from the testing space, although attentional wandering is impossible to eliminate completely. The point is that variations in startle may be due to a number of variables, with attention, arousal, and affect interacting with each other. Furthermore, these interactions may vary as a function of stimulus intensity, baseline arousal, personality, clinical characteristics, or a host of other factors. This means that methodology in a startle study must be very finely tuned and strictly controlled.

Using the Startle Response in Social and Personality Research

Overview

The startle response can be a useful measure in social and personality research. The fact that startle is affected by a variety of factors means that startle can be used to measure those factors. Startle provides a measure that is different from, but often correlated with, information provided from self-report questionnaires. Startle is a defensive response, and it has been effectively applied to the study of issues related to defensive motivation, such as fear and negative valence (Bradley, Codispoti, & Lang, 2006; Davis, 2006). However, startle is also an interruptive response, allowing for its application in research dealing with information processing, attention, and inhibitory processes (Braff, Geyer, & Swerdlow, 2001; Dawson, Schell, & Böhmelt, 1999; Graham, 1992). In the realm

of personality research, startle has been employed to study many issues, including traits of extraversion and neuroticism (Eysenck & Eysenck, 1985), harm avoidance (Cloninger, 1988), sensation seeking (Zuckerman, 1994), anxiety (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), and a variety of subclinical personality traits (Grillon & Baas, 2003). In the realm of social psychological research, startle has been used to study social phobia/social anxiety disorder (Larsen, Norton, Walker, & Stein, 2002; Marcin & Nemeroff, 2003), rejection sensitivity (Downey, Mougious, Ayduk, London, & Shoda, 2004), antisocial behaviors (Benning, Patrick, & Iacono, 2005), racial bias (Amodio, Harmon-Jones, & Devine, 2003), and anti-gay bias (Mahaffey, Bryan, & Hutchison, 2005). In addition, prepulse inhibition of the startle response has been used to investigate the effects of social isolation (Weiss & Feldon, 2001) and maternal care (Zhang, Chretien, Meaney, & Gratton, 2005) in rats, and social perception in humans with schizophrenia (Wynn, Sergi, Dawson, Schell, & Green, 2005). Similar methodology is used across many studies; we describe examples that are meant to be representative, but not comprehensive, of the work in this area.

Startle Reactivity

In studies using startle as a measure, we can look at the processing of the startle stimulus itself to see how this processing differs for different stimulus parameters, or between people with different characteristics. This constitutes a measurement of "startle reactivity," which is the measurement of the magnitude, amplitude, probability, and/or onset latency of the startle response. We can then compare measures of startle reactivity across stimulus parameters, participant groups, and so forth. One way in which startle has been used in the area of personality research involves simply measuring startle reactivity in people who score either high or low on certain personality questionnaires. For example, startle has been used to test Eysenck's hypothesis of differential excitability of the central nervous system in extraversion, by presenting startle stimuli to participants identified as introverts or extraverts. Blumenthal (2001) showed that startle responses were larger in introverts than in extraverts, and that direction of attention resulted in differential effects on startle as a function of extraversion (see Figure 6.2). As another example, patients with high levels of anxiety (Grillon, Ameli, Foot, & Davis, 1993) and with social phobia and panic disorder (Larsen et al., 2002) tend to have larger startle responses than nonanxious control participants do. This design involves simply comparing startle reactivity across groups, or across levels of a personality construct.

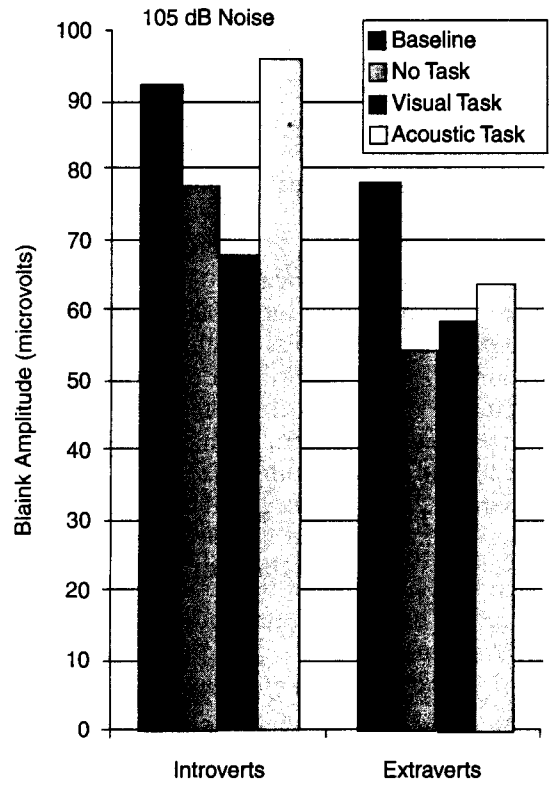

FIGURE 6.2. Difference in acoustic startle reactivity in introverts and extraverts as a function of attention directed to acoustic or visual tasks. From Blumenthal (2001). Copyright 2001 by the International Society for the Study of Individual Differences. Reprinted by permission.

A further step might involve quantifying the extent to which startle reactivity habituates across a session, by comparing startle reactivity on early and late trials. This can allow for the assessment of the degree to which habituation rate varies as a function of personality construct (LaRowe, Patrick, Curtin, & Kline, 2006). One caveat specifically related to the use of startle to investigate anxiety is the finding that potentiated startle is often not seen in patients with anxiety during baseline recordings; it is only seen when they are under a specific threat or contextual stress (Grillon & Morgan, 1999; Grillon, Morgan, Davis, & Southwick, 1998). This is an example of a personality construct interacting with the stimulus environment.

All of these cases involve measuring reactivity to the startle stimulus itself. However, we can complicate such a design by measuring startle in participants at different levels of a personality construct while presenting different intensities of startle stimuli, for example (Britt & Blumenthal, 1991, 1993). Alternatively, we can modify the pharmacological environment by administering caffeine or amphetamines to participants in one test session, but not in another (Flaten & Blumenthal, 1999; Hutchison, Wood, & Swift, 1999), or we can test clinical patients while they are or are not medicated (Duncan et al., 2006; Hamm, Weike, & Schupp, 2001). In all of these cases, differential reactivity to the startle stimulus can tell us something about the levels of the independent or classification variables of interest.

Fear-Potentiated Startle

If startle is elicited in the presence of a stimulus that has previously been repeatedly paired with an aversive unconditional stimulus, the startle response tends to be larger than if elicited in the presence of a neutral stimulus—a phenomenon referred to as "fear-potentiated startle" (Brown, Kalish, & Farber, 1951). In the original report of this effect, a light was repeatedly paired with a foot shock in rats, and when startle was subsequently elicited in the presence of that light, the response was larger in rats that had received the conditioning than in those that had not. This fear potentiation is an example of classical conditioning, with a previously neutral stimulus gaining conditional power based on its pairing with an unconditional aversive stimulus. The anatomical pathways underlying this effect have been identified (see Davis, 2006, for a review); as mentioned earlier, they involve a projection from the central nucleus of the amygdala to the brainstem startle center, the nucleus reticularis pontis caudalis. Using a conditioning procedure in humans very similar to that used in rats, Grillon and Davis (1997) showed that the eyeblink startle response could also be potentiated by stimuli that had been paired with shock. In fact, Grillon, Ameli, Woods, Merikangas, and Davis (1991) showed that presenting shock was not necessary, the threat of shock was sufficient to induce fear-potentiated startle. Importantly, to the extent that an experimenter's interaction with participants signifies a social situation, measuring startle reactivity as a function of social phobia (Larsen et al., 2002) may represent fear-potentiated startle. Similarly, researchers have experimentally induced fear of negative evaluation by having participants engage in an actual (Panayiotou & Vrana, 1998) or virtual (Cornwell, Johnson, Berardi, & Grillon, 2006) public speech task. Likewise, the emotion/valence studies described below may also partially represent fear-potentiated startle.

Startle can also be potentiated by corticotropin-releasing hormone (CRH), and this effect seems to be due to CRH reception in the bed nucleus of the stria terminalis (BNST), an area that is closely related to the amygdala (Alheid, deOlmos, & Beltramino, 1995). This led Walker and Davis (1997) to conduct experiments that resulted in their proposal of an animal model of anxiety that they referred to as "light-enhanced startle," caused by exposing rats to bright light for 20 min. Davis and colleagues (see Davis, 2006) showed that fear-potentiated startle depends on the amygdala, whereas anxiety-related startle depends on the BNST. Fear-potentiated startle appears to be faster and more stimulus-specific, whereas anxiety-enhanced startle develops more slowly, but remains in effect for a much longer time. The involvement of CRH in the enhancement of startle occurs outside the hypothalamic–pituitary–adrenocortical axis (Walker & Davis, 1997), and may be an indicator of the degree to which stress contributes to anxiety—an effect that can be measured with the startle response (Grillon & Baas, 2003). In fact, startle is enhanced by the conditional stimulus in fear conditioning (an example of cue conditioning), but also by the environment in which the conditioning took place (an example of context conditioning). This means that researchers may use startle as an indicator of the effectiveness of desensitization or extinction therapy, simply by measuring startle before and after such therapy in the presence of trigger (conditional) stimuli (de Jong et al., 1996; Vrana, Constantine, & Westman, 1992). This makes the measurement of the startle response a useful index of anxiety in patients dealing with various anxiety disorders, such as generalized anxiety disorder and posttraumatic stress disorder (Grillon & Baas, 2003). Startle is also a useful measure of state anxiety in nonpatients, in whom anxiety levels can be manipulated in the experimental setting (Britt & Blumenthal, 1993). The sensitivity of startle to variations in state anxiety means that researchers who are not specifically studying anxiety must be very careful to minimize anxiety-provoking stimuli in their testing environments.

The Emotion Probe: The Valence Match–Mismatch Hypothesis

The startle stimulus can be used to probe or evaluate ongoing processing, such as in the study of emotion, or to investigate the impact of social interaction on information processing. Here the startle probe is being used to evaluate the processing of information or situations that we researchers present to the participants. That is, we are not testing the stable characteristics of the participants, nor are we testing the various levels of an independent variable that we administer to modulate those characteristics. Instead, we are evaluating one process (e.g., defensive

motivation) by eliciting an automatic response that is sensitive to that process. Many studies in this area use the valence-matching method described by Vrana and colleagues (1988). This involves presenting startle stimuli while participants view slides that have been rated affectively positive, neutral, or negative. Startle is expected to be larger in the presence of negative slides than in the presence of positive slides. Some studies in this area compare startle reactivity during negative and positive slide conditions, while others compare startle reactivity during negative and neutral slide conditions, and also reactivity during positive and neutral slide conditions (see Lang, 1995, for more information about this procedure). Increased startle during negative slides can be thought of as a reaction to threat, similar to fear-potentiated startle (described above), and it involves the activation of aversive or avoidance motivation. Startle is a defensive response and can be used to index the activity of protective or avoidance motivation as follows: If a participant is experiencing a negatively valenced situation (which should be accompanied by an evaluation of unpleasantness) and a startle stimulus is presented, the ensuing startle response can be expected to be larger than the startle response elicited during a positively valenced, or pleasant, situation. When defensive motivation is increased by the unpleasant slide, the subsequent presentation of a startle stimulus will further increase activity in defensive responses, such as startle (Lang, Bradley, & Cuthbert, 1997). This affective modulation of startle has been used to investigate many personality constructs, including extraversion, harm avoidance, sensation seeking, and a host of others (Corr et al., 1995; Corr, Tynan, & Kumari, 2002). Similarly, this paradigm has also been employed to investigate such socially relevant constructs as rejection sensitivity (Downey et al., 2004), racial bias (Amodio et al., 2003), anti-gay bias (Mahaffey et al., 2005), and anti-social personality disorder (Benning et al., 2005).

In a study investigating the emotional modulation of startle, the interval between picture onset and startle stimulus presentation is an important consideration. The slide must be on for at least 500 msec before the startle stimulus is presented, in order to see differential startle reactivity as a function of slide content (Bradley et al., 2006). At shorter stimulus onset asynchrony, no valence effect is seen. Another important consideration is the degree to which the slides are rated as arousing. Studying the impact of a slide's valence on startle requires a slide with a relatively high level of rated arousal (Cuthbert et al., 1996). If slides are not rated as sufficiently arousing, startle will not vary as a function of the valence rating of the slides. This is a very important consideration, because the failure to find a valence effect may be due to some property of the participants or stimuli under study, but such a failure may also be due to insufficiently arousing slides. Many researchers in this area

use a standardized set of slides (Lang, Bradley, & Cuthbert, 2005) with arousal and valence ratings that have been empirically established.

Prepulse Inhibition

Another way in which startle has been used in the investigation of social and personality psychology involves the application of prepulse inhibition (PPI) methodology (see Blumenthal, 1999; Graham, 1975). This technique, at its most fundamental, involves measuring startle reactivity to identical eliciting stimuli on two types of trials: Some trials have only the startle stimulus (control trials), whereas other trials have the same startle stimulus preceded by a prepulse (prepulse trials). The prepulse can be in the same modality as the startle stimulus or in a different modality; in fact, it can be any detectable change in the background present during the session. Prepulses usually cause some degree of inhibition of the response elicited by the later startle stimulus; this phenomenon is called PPI (see Figure 6.3). Depending on stimulus parameters, this inhibition can be weaker (e.g., decreasing the response to the startle stimulus by 10%) or stronger (e.g., completely blocking the response to the startle stimulus). PPI is maximal when the onset of the prepulse precedes the onset of the startle stimulus by 60–240 msec (Graham & Murray,

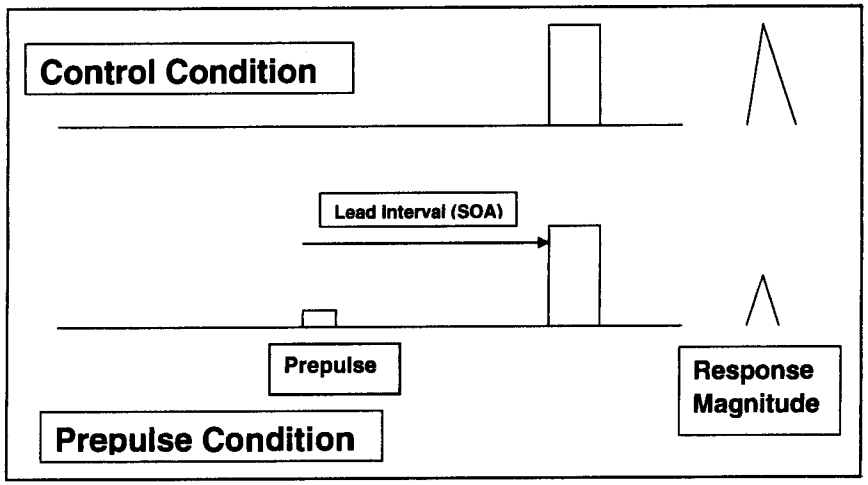

FIGURE 6.3. Schematic of the prepulse inhibition (PPI) method. Startle stimuli are identical in the control and prepulse conditions, with the only stimulus difference being the addition of a prepulse on some trials. Presence of the prepulse attenuates the response to the startle stimulus.

1977). The prepulse is often much less intense than the startle stimulus; indeed, the prepulse can be as weak as the detection threshold and still inhibit startle (Blumenthal & Gescheider, 1987; Reiter & Ison, 1977). Prepulses that are more intense, broadband, and longer result in greater PPI (Blumenthal, 1999). However, all that is required of a prepulse in order to inhibit startle is that it be a detectable change, with that detection occurring in the midbrain and not requiring conscious awareness of the presentation of the stimulus (Blumenthal, Burnett, & Swerdlow, 2001; Swerdlow et al., 2001). Paired pulse inhibition, in which two identical and intense startle stimuli are presented close together in time, can also result in PPI (Swerdlow et al., 2001).

PPI studies generally involve measuring the startle eyeblink reflex on control trials and prepulse trials, and then comparing the degree of PPI across groups or conditions. Some studies have failed to find expected PPI deficits, and this may be a function of symptom type, symptom severity, and medication history. In addition, three recently examined methodological factors have been shown to be important determinants of PPI. First, increased background noise has been found to decrease PPI, ostensibly due to increased sensory masking of the prepulse in the periphery (Blumenthal, Noto, Fox, & Franklin, 2006). Second, the related factor of signal-to-noise ratio (i.e., the ratio of the prepulse to background noise) has also been demonstrated to be an important determinant in PPI (Franklin, Moretti, & Blumenthal, 2007). These stimulus intensity relationships are important when investigating PPI, because when signal-to-noise ratio is too low (due to variations in either background noise or prepulse intensity settings), the effects of sensory masking are likely to introduce error variance into the study. Likewise, when the signal-to-noise ratio is too high, participants with "normal" PPI are likely to reach a ceiling of prepulse processing and allow participants who actually have sensorimotor gating deficits to approach similar PPI levels. Third, the way in which PPI is quantified can influence the outcome of PPI comparisons. Since baseline startle reactivity (i.e., startle reactivity in the control condition) varies greatly across individuals, this must be corrected for when PPI is quantified. Blumenthal and colleagues (2004) compared various methods for quantifying PPI, and concluded that the effects of baseline startle reactivity could be minimized by quantifying PPI as the proportion of difference; that is, (startle on prepulse trials – startle on control trials) / startle on control trials. However, since differences in baseline reactivity may exist as a function of personality/social traits or manipulations that may be of interest in the study, the researcher is advised to think about whether removing those baseline differences will remove the possibility of detecting such effects.

PPI is believed to reflect the extent to which the processing of the prepulse is protected from interruption by the startle stimulus (Graham, 1992). That is, the onset of the prepulse is believed to activate an inhibitory mechanism that decreases the subsequent impact of the startle stimulus, thereby decreasing the subsequent interruption caused by the startle response. Braff and colleagues (2001) describe PPI as an indicator of sensorimotor gating—an ability that is deficient in some clinical and preclinical groups, most notably in the schizophrenia spectrum (Braff, Grillon, & Geyer, 1992; Hazlett et al., 2007). For instance, PPI deficits have been found in patients with schizophrenia (Braff et al., 1978; Duncan et al., 2006), their first-degree asymptomatic relatives (Cadenhead, Swerdlow, Shafer, Diaz, & Braff, 2000; Kumari, Das, Zachariah, Ettinger, & Sharma, 2005), and asymptomatic individuals scoring high on schizotypal or psychosis-prone personality inventories (Cadenhead, Geyer, & Braff, 1993; Hazlett et al., 2003; Schell, Dawson, Hazlett, & Filion, 1995; Swerdlow, Filion, Geyer, & Braff, 1995). PPI has also been used to investigate state and trait anxiety, panic disorder, and social phobia (Duly, Hillman, & Coombes, 2007; Grillon & Baas, 2003; Larsen et al., 2002). Other research has demonstrated that PPI may be a useful measure of social processes, as studies have indicated that social isolation (Weiss & Feldon, 2001) and maternal separation (Zhang et al., 2005) in rats decrease PPI. Despite these promising findings, there has been little research concerning the effects of social factors and processes on PPI in humans. Nevertheless, further supporting the feasibility of this research, the proposed neural circuits for social information processing (Insel & Fernald, 2004; Nelson, Leibenluft, McClure, & Pine, 2005) overlap substantially with the neurological circuit for PPI (Swerdlow & Geyer, 1999). In addition, participants who display social information-processing deficits, such as those found in schizophrenia (Pinkham, Penn, Perkins, & Lieberman, 2003), also display PPI deficits (Hazlett et al., 2007). Indeed, Wynn and colleagues (2005) found a correlation between social cognition and PPI in a sample of patients with schizophrenia. Accordingly, this relationship should be examined in nonclinical participants and in other clinical groups. Moreover, PPI may be able to elucidate much about the psychophysiology of social processes if it is measured before, during, or after social interactions, or in relation to such things as social problem solving.

Attention-Modulated PPI

Researchers have also investigated the effects of attention on PPI, using approaches based primarily on the method described by Filion, Dawson, and Schell (1993). This method involves presenting tone prepulses at two or more frequencies, with these tones lasting several seconds. At some time after tone onset (e.g., 60–240 msec), the startle stimulus is presented. Participants are told to count the tones of one frequency that are longer than the other tones of that frequency—a task called the "discrimination-and-counting task." This makes tones of one frequency targets and tones of the other frequency nontargets, with the trials containing the latter often referred to as "ignore" trials. Several studies have shown that PPI is more pronounced on trials with target prepulses than on those with nontarget prepulses (e.g., Dawson, Hazlett, Filion, Nuechterlein, & Schell, 1993; Jennings, Schell, Filion, & Dawson, 1996; Thorne, Dawson, & Schell, 2005). This attentional modulation of PPI has been shown to be absent in patients with schizophrenia (Hazlett et al., 2007), suggesting an attentional deficit in these patients.

Not all studies in this area report such an attentional modulation of PPI, and the detection of an attention effect may be dependent upon a specific combination of methodological decisions. For example, Hawk, Redford, and Baschnagel (2002) found that only participants who were promised that they would be paid according to their accuracy on the attention task displayed attentional modulation of PPI. Other researchers have failed to find attentional modulation when background noise is presented throughout the session (background noise is used in many studies of PPI, with a 70-dB broadband noise often being presented throughout the entire session; Franklin, Fox, & Blumenthal, 2006). It may also be the case that the discrimination-and-counting task is required for the attentional modulation of PPI, since the effect is less reliably seen with other tasks (Heekeren, Meincke, Geyer, & Gouzoulis-Mayfrank, 2004). In sum, it appears that PPI can be used to investigate the effects of attention if this particular methodological combination (paid participants, no background noise, discrimination-and-counting task) is used. In addition, because attentional effects are only detected under specific methodological conditions, researchers need not worry that undirected attention will influence their results whenever this particular methodological combination is not used.

Although to date attention-modulated PPI has rarely been utilized in social and personality research, this paradigm does have the potential to provide insight in these areas. As mentioned earlier, the passive PPI paradigm may be able to index the functioning of the neural circuits of social information processing at rest; however, because it specifically assesses the ability to direct attention to a stimulus, attention-modulated PPI may be a more sensitive measure of processes that rely on the integrity of executive functioning, such as social problem solving. Similarly,

attention-modulated PPI may be a more sensitive index of executive functioning deficits related to Cluster B personality disorder constructs.

Experimental Design Considerations

Overview

Many experimental design conditions have been described in the preceding sections of this chapter. In this section, we reiterate some of those and mention a few other things that the researcher should consider or keep in mind. These suggestions have to do with aspects of the experimental setting, the preparation of the participant, the collection of data, and the processing of those data. Most of these have to do with the fact that startle is sensitive to many things, and a failure to control as many of those things as possible will allow them to become influential in the data—either inducing real effects of uncontrolled variables (confounds), or simply adding to the error in the data set. Some of these suggestions have been empirically investigated, whereas others are based simply on our experience of measuring startle in many participants while investigating a variety of research questions.

Effect Size

One issue to consider is the effect size of the personality variable of interest. Differential startle reactivity as a function of a personality construct may not be evident if a relatively small group of participants is studied and a median split based on personality scale responses is conducted (Blumenthal, 2001). If the personality effect is weak, the researcher may decide instead to screen a large group of potential participants and select those scoring in the extreme high and low ranges of the questionnaire. The point is that a failure to find an effect of the personality variable on startle may be due to an absence of a difference between personality subgroups, or to a small effect size. Of course, this point is not unique to startle, but applies to any study of personality differences. As an alternative to comparing startle reactivity in people who score high or low on a personality questionnaire, a researcher may be able to get a more sensitive look at the relationship between startle and the personality construct by assessing the correlation between startle reactivity and scores on the personality questionnaire (Bowker, Franklin, & Blumenthal, 2007). To the extent that a significant correlation is found, the two measures—brainstem reflex and personality—may reflect an underlying relationship.

Experimental Setting

With regard to the experimental setting, researchers should put themselves in the place of the participant and try to take as fresh a look as possible at the testing environment. Is there anything potentially intimidating or anxiety-provoking in the testing room that does not need to be there? For example, some researchers inject conducting paste into their recording electrodes with a syringe, an effective way of filling the electrode cup with paste. If that syringe is left on a table or shelf in the testing room, within sight of a participant (or, worse, if the paste is injected into the cup within sight of the participant), the presence of the syringe may increase anxiety, which may increase startle reactivity. This would constitute an accidental manipulation of anxiety, with subsequent impact on startle. Are there pictures or decorations in the lab that the participants could consider either unpleasant (which may increase startle reactivity) or interesting and attention-getting (which may decrease startle reactivity)? Being observed by others may make some participants anxious, so the presence of an observation window or even a closed-circuit camera may cause a problem (Cacioppo, Rourke, Marshall-Goodell, Tassinary, & Baron, 1990). Of course, being able to see the participant is often important, and is sometimes required by the local human subjects committee. Also, the extent to which a participant hears external sounds such as other people talking or walking down the hall can be distracting (attention) or sensitizing (anxiety); testing in a sound-attenuated room will decrease this problem. If sound attenuation is not possible, the researcher may consider presenting a background noise throughout the session, to mask extraneous noises that are less intense than this background noise (a noise of 70 dB(A) is typically used). However, this background noise can influence both startle reactivity and startle PPI (Blumenthal et al., 2006; Franklin et al., 2007).

Data Collection

When researchers are measuring startle eyeblink reflexes, the way in which the recording electrodes are placed on the skin below the eye is an important consideration (see Blumenthal et al., 2005). The goal of electrode placement is to obtain a reliable EMG signal from the orbicularis oculi muscle under the skin just below the eye. Some researchers, in order to get as pure and strong a signal as possible, use abrasive pads to remove surface oil, makeup, dirt, and often epidermis; such abrasion can be quite uncomfortable for some participants. Given the sensitivity of startle to unpleasantness, this abrasion procedure may influence the data. Also, considering the fact that most participants know very

little about psychophysiological measurements, and also know very little about the electrochemical signals that their bodies produce, referring to the recording electrodes as "electrodes" may heighten anxiety and/or arousal in some participants. They may have the impression that the presence of "electrodes" will mean that they will receive electric shocks, and participants have heard enough about both electric shock and deception in "psychology experiments" for this false belief to increase anxiety in some cases. Researchers might rather refer to these electrodes instead as "sensors"—a distinction that may not seem important to the researchers, but may be important to naive participants. Again, such a seemingly minor point may have a more pronounced influence on participants at some level of a personality construct (e.g., trait anxiety) than on those at another level of that same construct, and this confound may be impossible to extract from the data.

Another consideration is the fact that the shape of the orbit, and its relation to the cheek, vary across participants: Some people have eyes that are further forward; some have eyes that are deeper in the orbital sockets; some have cheeks that are higher or wider; and so forth. The goal is to place the electrodes in as nearly the same place as possible on each participant. This is especially important when data are collected from the same participant at two points in time, or from both sides of the face at the same time.

The way in which a researcher interacts with a participant also may have an impact on the data. It is often a good idea to make participants as comfortable as possible, and this will be facilitated by experienced, well-trained, and polite researchers. This may seem to the reader both obvious and not worth mentioning—but again, the sensitivity of startle to a variety of factors suggests that variations in the participants' state, which can be influenced by their evaluation of the testing situation, can influence the data. Something that is considered a threat to one person may be irrelevant to another person; also, something that one person attends to may escape the notice of another person. In both cases, startle reactivity may be influenced more in one person than in the other. An extreme example of the extent to which what a participant believes, thinks, or expects has an influence on the data can be seen in research in which placebo responses are evident in startle data. Specifically, caffeine increases startle reactivity, but so does the presentation of decaffeinated coffee when a participant believes that the coffee is caffeinated (Flaten & Blumenthal, 1999). Another example involves increased startle when participants are told that a puff of air is directed "toward the eye" versus "toward the ear," when in fact the air puff delivery tube was directed to the same point between the eye and the ear in all cases (Haerich, 1994). This issue also highlights the fact that it may be necessary to deceive

the participants in some cases, depending on the experimental question under study. Of course, such deception must be justifiable to the local human subjects committee.

Interpretation of Results

When designing a study and when interpreting the data from that study, a researcher must pay special attention to the possibility of uncontrolled factors. Since startle varies as a function of several factors, the more the researcher knows about the participants, the better. Knowledge of which medications they use; whether they use tobacco, caffeine, or other psychoactive substances; whether they are withdrawn from any of these substances at the time of testing; whether they have normal sensory sensitivity—all of these factors may be as influential as the personality or social construct under study. That is, something as simple as the fact that some participants use tobacco and others do not may have a larger effect size than whether the participants are introverted or extraverted, for example. This does not mean that startle is not useful in personality and social psychology research; it just means that startle must be used carefully.

Conclusions

Startle is affected by many events and qualities in the environment (stimulus parameters, background noise, multisensory input, etc.). It is also affected by numerous characteristics of the individual (personality, clinical conditions, pharmacological composition, sensory sensitivity, etc.), as well as by many processes of the individual (emotion, attention, arousal, etc.). The dividing lines among these three categories are not perfectly defined, and a good deal of interaction occurs. With these cautions in mind, there is a very high likelihood that the use of startle measures in social and personality research will continue to contribute information that is based on established physiological systems, leading to a fuller understanding of the mechanisms that determine many of the constructs underlying social and personality psychology.

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