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Timing Affect: Dimension-Specific Time-Based Expectancy for Affect

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Affective information in our environment is often predictable by time; for example, positive answers are typically given faster than negative ones. Here we demonstrate, for the first time, that humans can implicitly adapt to time-based affect predictability. Participants were asked to categorize words, with the words' irrelevant valences being predictable by the timing of their occurrence. Adaptation to this pattern became evident by better performance for typical combinations of time and valence, relative to atypical combinations (Experiment 2). A comparable adaptation was observed for predictable activation (another affective dimension, Experiment 4), but not for predictable imageability (a nonaffective dimension, Experiment 3). In none of the experiments did participants become aware of the time-based predictability. These findings have significant implications for our theoretical understanding of human time-based expectancy, as well as important implications for the scheduling of system delays in artificial interaction and communication environments.

Keywords: time-based expectancy, emotion, expectation, preparation, anticipation

Affect impacts massively on cognitive processing. Affective processing can interfere with or bias almost any cognitive capacity we have, from low level visual processing (Anderson, 2005; Padmala & Pessoa, 2008) to complex problem solving (Spering, Wagener, & Funke, 2005; Schimmack & Derryberry, 2005). Indeed, affective and cognitive processing are so deeply entangled that some authors have even suggested abandoning altogether the traditional emotion/cognition distinction (Inzlicht, Bartholow, & Hirsh, 2015; Pessoa, 2008). The strong coupling between affective and cognitive processing has attracted fast-growing research interest in recent years (Buodo, Sarlo, & Palomba, 2002; Dreisbach & Fischer, 2012b, 2015; Dreisbach & Goschke, 2004; Goschke & Bolte, 2014; Kunde & Mauer, 2008), which has been accompanied by increasing coverage in the popular media (Belsky, 2016; Hoffman, 2015; Lumma & Nagel, 2016; O'Connor & Joffe, 2014; Pykett, 2015). This is not surprising, given the prevalence of affective stimulation in our everyday life interaction environments. Consider, for example, searching for information on the Internet while emotionally charged advertisements constantly attempt to distract attention from one's actual search goals.

One of the most interesting and most intensely researched issues in this context concerns the question: which factors modulate the impact of affective processing on cognition? Which factors determine whether irrelevant affective stimulation has profound or negligible effects on cognition? This issue has traditionally been approached in several areas of applied psychology, yet from very different perspectives: marketing and advertising psychology, for instance, is interested in instruments for amplifying the emotional impact of advertisements (Cockrill & Parsonage, 2016; Das, Galekh, & Vonkeman, 2015; Holbrook & O'Shaughnessy, 1984), while clinical or work psychology often attempts to increase the ability to shield goal directed cognitive processes from interference by counterproductive emotional processing (Achtziger, Gollwitzer, & Sheeran, 2008; Toli, Webb, & Hardy, 2016). However, during the past two decades or so, basic research on modulating affective-cognitive interaction has also become a highly proliferative research area (see Iordan, Dolcos, & Dolcos, 2013; Williams, Mathews, & MacLeod, 1996, for reviews).

One particularly important factor modulating affective-cognitive interaction is expectancy. Our cognitive system is essentially anticipative on every level (Clark, 2013; Hohwy, 2016). This means we are extremely sensitive toward predictive relationships in our environment, and are highly versatile in exploiting these relationships behaviorally (Gilbert & Wilson, 2007). This is, of course, also true for predictable affect. Numerous studies have shown that several physiological responses differ for the perception of expected and unexpected affective stimuli (Lin, Xiang, Li, Liang, & Jin, 2015; Nitschke, Sarinopoulos, Mackiewicz, Schaefer, & Davidson, 2006; Onoda et al., 2006; Wieser, Reicherts, Juravle, & von Leupoldt, 2016). This confirms our sensitivity to the predictability of affect, and shows that we can anticipate affective stimulation.

However, the more important question is: what does this anticipation do to our cognitive system? Does the anticipation of irrelevant affect improve or impair our cognitive processing? Our knowledge on this issue is surprisingly sparse, given the central importance of anticipation in cognition. To our knowledge, the

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only previous studies on affect anticipation and cognition are those of Kleinsorge (2007, 2009). In his experiments, participants solved math equations superimposed on valent or nonvalent pictures. Explicit cues were displayed prior to target stimuli. The cues predicted the valence of the pictures, but were not predictive concerning the equations. Participants were instructed to exploit the cues to improve their performance. However, results showed that performance was actually impaired by anticipation of negative valence, relative to conditions with unexpected valence or anticipation of neutral or positive valence. These findings suggest that advance information about irrelevant negative affect is rather counterproductive, while information of irrelevant positive affect does not affect cognition.

However, Kleinsorge's studies are not representative of most affective predictability relations in our everyday life environments. Affect is only rarely announced by explicit cues, neither is one typically urged to intentionally exploit such cues to improve behavior. In most situations, information about upcoming affect can be extracted implicitly from the distribution of environmental events rather than from explicit cues. A particularly informative source for implicit anticipatory information is redundancy in time-event patterns: often, the flow of time predicts which affect to expect next. For example, a longer waiting time for a computer response changes our expectancy from anticipating a positive success message to a frustrating error message (Shahar, Meyer, Hildebrandt, & Rafaely, 2012). Likewise, a slightly prolonged interturn silence, in verbal communication, changes expectancy from a positive to a negative answer (Roberts & Francis, 2013; Roberts, Margutti, & Takano, 2011; Roberts & Norris, 2016). Although such temporal patterns strongly shape our behavior, we are typically not aware of them, and do not intentionally aim at adapting to them (Aufschnaiter, Kiesel, Dreisbach, Wenke, & Thomaschke, in press).

In the present study, we investigate how the anticipation of irrelevant affect from implicit temporal cues affects cognitive performance. Before we introduce the study's design in more detail, we locate our approach in the literature by briefly introducing different human timing capacities, and reviewing previous studies about affective influences on these capacities.

Human Timing

Human timing is currently intensely researched in cognitive psychology (Block & Grondin, 2014), the major topics being time estimation, and time expectancy (Grondin, 2008; Nobre & Coull, 2010; Wearden, 2016). However, the phenomenon investigated in the present paper—using time as a *source* of expectancy—belongs to neither of these areas. We do not let participants explicitly estimate the intervals upon which they base their affect expectancies, nor do participants expect certain time intervals in our study. Instead they expect affect, and they *base* these affect expectancies on time intervals. Nevertheless, time estimation and time expectancy become relevant to the interpretation of our findings (see Discussion). Thus, we briefly introduce these areas here.

Estimating Time

Time estimation is typically studied within either reproduction or bisection paradigms (see, however, Brown & Stubbs, 1988; Droit-Volet & Wearden, 2015; Wearden, 2015; Wittmann, 2011, for alternative designs). In reproduction experiments, participants are exposed to an interval, for example, the duration between two short successive beeps or light flashes, and afterward have to press a button for as long a time they felt the interval lasted (Wackermann & Ehm, 2006; Woodrow, 1930). In the bisection paradigm, an interval has to be classified as shorter or as longer than a similar comparison interval (Allan & Gibbon, 1991; Bausenhart, Bratzke, & Ulrich, 2016; Kopec & Brody, 2010). This allows estimating a point of subjective equality, where both intervals are perceived to be about the same duration.

Time estimation, operationalized by these paradigms, is influenced by a variety of factors. For example, auditory stimuli are judged as being longer than visual stimuli (Wearden, Edwards, Fakhri, & Percival, 1998), filled auditory intervals appear longer than empty ones (Wearden, Norton, Martin, & Montford-Bebb, 2007), and lower frequency tones have a seemingly longer duration than high frequency tones (Yoblick & Salvendy, 1970). Despite a general agreement on these behavioral patterns, it is currently heavily debated which type of "internal clock" underlies them (Machado, Malheiro, & Erlhagen, 2009; Simen, Balci, deSouza, Cohen, & Holmes, 2011; Wittmann, 2013).

Expecting Time

As described above, in our study, time functions as a *source* of expectancy: the duration of an interval triggers expectancy concerning the following event. Yet, in most previous studies on time and expectancy, time has figured as a *target* of expectancy: One expects an interval to *have* a certain duration.

Those expectancies for an interval are commonly investigated by the so called foreperiod paradigm. In a foreperiod paradigm, a target stimulus is preceded by a warning stimulus. The interval between warning stimulus and target—the foreperiod—is systematically manipulated, leading to different duration expectancies. A central finding is that responses with constant intervals are on average faster than with randomly varying intervals (Cardoso-Leite, Mamassian, & Gorea, 2009; Los, Knol, & Boers, 2001) because, with constant intervals, participants can build reliable expectancies for when the target will appear (Los & Schut, 2008; Rolke, 2008; Rolke & Hofmann, 2007; Rolke & Seibold, 2010). When intervals are constant within a block of trials performance steadily deteriorates with longer interval duration (Seibold, Bausenhart, Rolke, & Ulrich, 2011; Seibold, Fiedler, & Rolke, 2011; Seibold & Rolke, 2014; Steinborn, Langner, & Huestegge, 2016) whereas, for variable intervals, performance continuously improves with longer interval duration (Steinborn, Rolke, Bratzke, & Ulrich, 2009, 2010; Van der Lubbe, Los, Jaśkowski, & Verleger, 2004). It is currently debated whether the latter effect is due to trace conditioning processes (Los, 2010; Los, Kruijne, & Meeter, 2017; Steinborn, Rolke, Bratzke, & Ulrich, 2008), or to the conditional probability for immediate target occurrence continuously increasing while the interval passes by (Janssen & Shadlen, 2005; Vallesi, 2010).

With variable intervals, the interval can also be announced by explicit duration cues (Coull, 2009; Coull, Nobre, & Frith, 2001). Target responses are usually faster and more accurate when the targets were validly cued relative to when the cue was invalid (Correa, Lupiáñez, & Tudela, 2005; Correa, Sanabria, Spence, Tudela, & Lupiáñez, 2006). The time-cueing paradigm is well established in behavioral psychology (Correa, Cappucci, Nobre, & Lupiáñez, 2010; Correa, Lupiáñez, Milliken, & Tudela, 2004), but also figures as one of the major paradigms in neuroscientific studies on timing (Coull, Cheng, & Meck, 2011; Coull & Nobre, 1998).

Some studies have compared expectancy for an event with expectancy for an interval. For example, in a study by Kingstone (1992), one part of a combined cue predicted the target stimulus' orientation, while the other part predicted the duration of the interval between cue and target. Note that this design essentially differs from that employed in the present study because, in Kingstone's paradigm, events were not predicted by the duration of the interval, but by a part of the combined cue. Kingstone observed performance gains for validly predicted orientation, as well as for validly predicted interval duration.

Time-Based Expectancy

Only recently, researchers have investigated how time functions as a *source* of expectancy, instead of being expected itself (Wagener & Hoffmann, 2010). This form of expectancy is commonly referred to as time-based expectancy, and is typically investigated within the time-event correlation paradigm. The time-event correlation paradigm is a special type of the foreperiod paradigm: it involves two different warning interval durations and two different targets, with both intervals and both targets appearing equally often. Neither the target nor the intervals are explicitly cued. Thus, in advance of a trial, participants cannot expect how long the interval will be or which target will be presented. But, interval-target *combinations* are imbalanced: One target appears more frequently after the short than after the long interval, whereas the other target appears more frequently after the long than after the short interval. Thus, targets are correlated with intervals. Typically, participants do not become aware of this regularity, but quickly adapt to it: Responses to frequent interval-target combinations are faster than responses to infrequent ones. Thus, targets are cued *implicitly* by interval duration.

When target and response are both predictable by interval duration, participants seem to develop time-based expectancies primarily for responses (Thomaschke & Dreisbach, 2013), as well as for those target features that are response relevant (Thomaschke, Hoffman, Haering, & Kiesel, 2016). In more complex designs, time-based expectancy has also been observed for tasks in a task switching environment (Aufschnaiter et al., in press), and for target-distractor congruency in an Eriksen Flanker task (Wendt & Kiesel, 2011). Thomaschke and Dreisbach (2015) have suggested a cognitive model of time-based expectancy, drawing on previous models of trace conditioning (Los et al., 2001; Machado, 1997). According to this model, perception of the warning interval triggers a cascade of successive time representations, running in synchrony to the interval, each representing an individual duration. Whenever a target appears, excitatory connections, from the currently active time-representation to those neural populations that generate expectancy for processing this target, are strengthened. After some practice, this has the effect that each time-representation automatically triggers expectancy for those targets that appeared particularly frequently after that time (see Los, Kruijne, & Meeter, 2014, for an alternative model).

In the present study, we investigate whether time-based expectancy can also be directed at processing affective aspects of a target.

Affect and Timing

Affective influences on timing are a major topic in current timing psychology (Halbertsma & Van Rijn, 2016; Langner, Steinborn, Chatterjee, Sturm, & Willmes, 2010; Lui, Penney, & Schirmer, 2011; Matthews et al., 2002; Schirmer, Ng, Escoffier, & Penney, 2016); for reviews see Droit-Volet and Gil (2009); Droit-Volet, Fayolle, Lamotte, and Gil (2013); Lake (2016); Lake, LaBar, and Meck (2016). However, researchers have exclusively focused on time estimation behavior, with no previous studies on the relation between affect and time expectancy or time-based expectancy.

A typical finding is that the duration of emotional pictures is estimated as being longer than the duration of neutral pictures (e.g., Kliegl, Watrin, & Huckauf, 2015). Among emotional pictures there seems to be an interaction of the affective dimensions valence and activation, with regard to experienced duration. For pictures with low activation, negative pictures are perceived as being displayed longer than positive ones. For pictures with high activation, this relation is reversed (Angrilli, Cherubini, Pavese, & Mantredini, 1997, see also Pfeuty, Dilharreguy, Gerlier, & Allard, 2015). Such an interaction has, however, not been observed for auditory stimuli, where effects of valence and activation were independent: negative sounds were experienced as being longer than positive ones, and strongly activating sounds were perceived as being longer than less activating sounds (Noulhiane, Mella, Samson, Ragot, & Pouthas, 2007). Such effects have frequently been replicated and are now so well established that time estimation is employed as an implicit measure for emotional reactivity (Gros et al., 2015, 2016). Note, however, that emotional effects on time estimation can be reduced when one is aware of them (Droit-Volet, Lamotte, & Izaute, 2015).

Although we do not explicitly access participants' time estimation skills in the present study, the recognition of different intervals is a precondition for basing affect expectancies on interval duration. Thus, one of our control experiments was inspired by the aforementioned literature on affective dimensions and their differential impact on timing.

Affective Dimensions

Most current theories of affect assume that affective states can be classified along two major dimensions: valence and activation (Lang, Greenwald, Bradley, & Hamm, 1993; Russell, 1980). Valence refers to subjective positive or negative experience (Lang, Bradley, & Cuthbert, 1990). Activation is associated with the sympathetic nervous system, and refers to the subjective experience of being activated or deactivated (Russell, 1980). There is now ample accumulative evidence that valence and activation can be independently manipulated and are dissociated at the behavioral and neuronal level (Anderson et al., 2003; Delaney-Busch, Wilkie, & Kuperberg, 2016; Dolcos, LaBar, & Cabeza, 2004; Kensinger, 2004). However, both dimensions can also interact in various ways (Kuppens, Tuerlinckx, Russell, & Barrett, 2013). Consider, for example, the activation modulation of valence effects on time estimation, described above (Angrilli et al., 1997). Such interactions are also reflected in the numerous stimulus databases which have been standardized for valence and activation: the relation between the dimensions is typically U-shaped, high activation going along with relatively strong positive or negative valence (Bradley, Codispoti, Cuthbert, & Lang, 2001; Kuppens et al., 2017; Võ et al., 2009; Võ, Jacobs, & Conrad, 2006).

We focus on time-based expectancy for valence in the present paper. But, because of the known interrelations between both dimensions, we also test for time-based expectancy for activation, to access the dimensional specificity of time-based affect expectancy.

Aim of the Present Study

The general aim of the study is a systematic investigation of the previously unexplored relation between affect and time-based expectancy. More precisely, we test the hypothesis that time-based expectancy can be formed for task-irrelevant stimulus valence, in the sense of expecting positive stimuli after one of two interval durations, and negative valence after the other. Furthermore, we dissociate time-based valence expectancy from activation expectancy, and we investigate whether it facilitates or impairs a cognitive task.

General Method

Overview

In four experiments, we investigated time-based expectancy for task-irrelevant stimulus valence. Participants were asked to classify the grammatical gender of positive or negative visually presented nouns, which were preceded by one of two possible warning intervals.

In Experiment 1, interval duration did not predict word valence. The purpose of this experiment was to check whether there exists a natural mental association between valence and duration. Experiment 2 instantiated a time-event correlation paradigm, meaning that interval duration predicted word valence. In Experiment 3, we controlled whether time-based expectancy can also be formed for a nonaffective word property: duration predicted imageability of the target words. Finally, Experiment 4 tested whether time-based expectancy can be built for irrelevant activation.

Participants

Participants were students of Regensburg University. For participation, they received a course credit. They were naïve as to the purpose of the experiments. Each of them participated in only one of the experiments. They reported having normal or corrected to normal vision. Each participant gave informed consent prior to the experiment. To determine the appropriate sample size we performed a power analysis for a minimal power level of .8, and an α–level of .05. Based on previous studies on time-based expectancy, we assumed a medium effects size of Cohen's $d = 0.5$. The power analysis yielded a minimal sample size of 27. To fully counterbalance all factors we rounded the sample size to 30 participants in each experiment.

Apparatus and Stimuli

Participants sat in a dimly lit room facing a computer screen (19″ diagonal) at a viewing distance of approximately 50 cm. Responses were collected via the "y" and "m" keys of a standard QWERTZ keyboard, positioned centrally on the table in front of the participants. The experiment was run by the program E-Prime (Schneider, Eschman, & Zuccolotto, 2002), Version 2.

Target words were a displayed in white font "Arial," size 24, presented centrally against a black background. The warning stimulus was the plus sign (Measuring 1 × 1 cm). Error messages were displayed in red. The background color was black throughout the entire experiment.

We have chosen words as target stimuli, because they are among the most frequently employed stimuli in the affective sciences, and there exists a considerable number of databases, precisely controlled for valence and activation (see also General Discussion). Several previous studies have shown that word valence is automatically processed, even when it is task-irrelevant (e.g., Thomas, Johnstone, & Gonsalvez, 2007; van Hooff, Dietz, Sharma, & Bowman, 2008).

In the present study, we used words from the Berlin Affective Word List Reloaded (BAWL-R, Võ et al., 2009).This is a list of 2902 German words, which were rated by 200 participants with regard to valence, activation and imageability. Valence was rated on a scale from −3 (*very negative*) to 3 (*very positive*). Activation was rated using a Self-Assessment Manikin (Lang, 1980) on a scale from 1 (*no activation*) to 5 (*high activation*). In addition, the nonaffective dimension imageability was rated from 1 (*low imageability*) to 7 (*high imageability*).

The database includes 2107 nouns. In German, each noun has a grammatical gender: female, male, or neutral. All nouns with a grammatical gender unambiguously female or unambiguously male have been considered as potentially valid stimuli.[1] From this set we selected different kinds of subsets with extreme scores on different scales. In Experiments 1 and 2 words with extreme valence were selected. In Experiment 3, words with extreme imageability and moderate valence were chosen. In Experiment 4, words had an extreme activation level (see below).

Procedure

The task was to classify the target words' grammatical genders as female or male. Grammatical gender can neither be directly derived from the referent's real life gender, nor from the nouns' endings. For male or female referents, there is a correlation between gender and grammatical gender, but for neutral referents (the vast majority of the nouns used here) the assignment of grammatical gender appears arbitrary (Whittle, 2011). It can be predicted from the noun's ending with a probability of under 80% (Duke, 2009). Thus, by emphasizing accuracy in the instruction, we were able to preclude nonsemantic strategies.

Each trial started with the display of a fixation cross for either 600 or 1800 ms (the warning interval) followed by a noun (the

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[1] We did not use nouns that exist in a female and male format, because this would allow for strategies such as simply processing the ending of the word (e.g., a male student in German is a "Student" a female student is called "Studentin." Example for neutral referents are "Katze" (cat) which is female in German and "Hund" (dog) which is male.

target stimulus, see Figure 1). Participants responded by a left or right button press according to the noun's grammatical gender. The mapping from gender to button was constant throughout the experiment, but counterbalanced across participants. The word remained visible until a response was detected. When participants responded incorrectly, or before the noun was displayed, an error message was presented for 3000 ms. After each trial there was an empty intertrial interval of 500 ms.

In each experiment, participants classified 600 words. The order of the words for randomized separately for each participant. However, the duration of the warning interval was—depending on experiment—not completely randomized (see the Method sections for individual experiments).

The experiment comprised 4 blocks of 150 trials each. Blocks were separated by self-paced pauses. The experiment was followed by a short interview, inquiring whether participants noticed any regularity during the procedure. The interview comprised of two parts. In the first part participants were asked to elaborate in as much detail as possible on any regularity they recognized in the experimental procedure. In the second part they were informed that there was a regularity involving the warning intervals. They were asked to elaborate in a much detail as possible their best guess concerning the mentioned regularity involving the warning intervals.

The entire procedure lasted approximately 40 mins. Participants were not informed about the predictive value of the intervals prior to the experiment.

Data Screening and Analyses

We analyzed only Blocks 2 to 4, because Block 1 was considered practice. The three first trials of each block, as well as the trials following errors, were excluded from all analyses. For the response time analyses, trials with errors were removed. These were 3.74%, *SD* = 1.9, in Experiment 1, 3.18%, *SD* = 2.5, in Experiment 2, 3.37%, *SD* = 1.3, in Experiment 3, and 3.52%, *SD* = 2.4, in Experiment 4. We also excluded from response time analyses trials with response times deviating more than 3 *SD*s from their individual cell mean. These were 2.03%, *SD* = 0.39, of the nonerror trials in Experiment 1, 1.91%, *SD* = 0.34, in Experiment 2, 1.83%, *SD* = 0.41, in Experiment 3, and 2.00%, *SD* = 0.42, in Experiment 4.

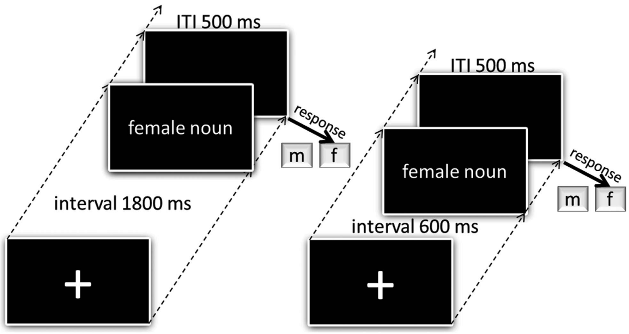

Figure 1. Schematic illustration of trial structure with a long (left panel) and a short (right panel) warning interval. In both example trials, the target stimulus is a female noun, and "female" has been mapped to the right response button. Thus, participants are required to respond with the right button in both example trials.

Experiment 1: Baseline

We presented extremely positive and extremely negative words after a short and a long interval. The order of interval and of valence was randomized and there was no correlation between interval and valence.

The purpose of Experiment 1 was to investigate whether there is an a priori association between warning interval and valence. By an a priori association, we mean an association that the participants acquired prior to the experiment during real life natural language processing. In natural conversations, short pauses are more often followed by positive expressions, while relatively longer pauses are more often followed by negative expressions (e.g., Roberts et al., 2011, see also Introduction). Although the experimental procedure strongly abstracts from natural conversations, participants might tend to expect a positive word after a short, and a negative word after a long interval.

However, we also hypothesize that participants respond overall faster to positive than to negative valence, irrespective of the interval. This advantage of positive stimuli has frequently been observed in previous studies with task-irrelevant stimulus valence (Estes & Adelman, 2008a, 2008b; Kuperman, Estes, Brysbaert, & Warriner, 2014; Wentura, Rothermund, & Bak, 2000).

With regard to time expectancy, we hypothesize that participants respond generally faster after the longer than after the shorter interval, irrespective of valence. This asymmetry is a common finding with randomly varying intervals (see Los & Heslenfeld, 2005; Steinborn & Langner, 2012; see also the Introduction).

Method

Participants. Thirty subjects participated in the experiment. Twenty participants were female, 10 were male. Three were left-handed, 27 were right-handed. One participant preferred not to report his age. The mean age of the other participants was 22.52, *SD* = 4.21, range = [18, 38].

Apparatus and stimuli. We chose the words with the most extremely positive and extremely negative valence from all eligible female and male nouns (see General Method). In particular, the set of negative words was composed of the 150 female nouns with the lowest valence rating, *M* = −1.81, *SD* = 0.40, range = [−2.90, −1.25], and the 150 male nouns with the lowest valence rating, *M* = −1.86, *SD* = 0.39, range = [−2.90, −1.30], resulting in a set of 300 negative words, *M* = −1.83, *SD* = 0.39, range = [−2.90, −1.25]. The set of positive words was composed of the 150 female nouns with the highest valence rating, *M* = 1.82, *SD* = 0.36, range = [1.40, 2.90], and the 150 male nouns with the highest valence rating, *M* = 1.69, *SD* = 0.31, range [1.30, 2.60], resulting in a set of 300 positive words, *M* = 1.76, *SD* = 0.34, range = [1.30, 2.90]. The total set of stimulus words had a mean valence of −0.04, *SD* = 1.83.

Procedure. Interval duration and valence were not correlated (i.e., there was the same number of positive and negative words after the short and the long interval).

Results

One participant was excluded from analysis because of an error score, 28.10%, more than 4.9 *SD*s (4.82) above the mean, 4.55%. Mean response times and error rates were calculated for each combination of Block, Interval and Valence (see Figure 2).

Response times. We conducted a $3 \times 2 \times 2$ repeated measures ANOVA on mean response times with the factors Block (1 to 3), Interval (short vs. long), and Valence (positive vs. negative). Neither Block, $F(2, 56) = 1.63$, $p = .205$, $\eta_p^2 = .055$, nor Interval, $F(1, 28) = 1.04$, $p = .317$, $\eta_p^2 = .036$, was significant. However, participants responded significantly faster to positive, 835 ms, $SD = 130$, than to negative words, 897 ms, $SD = 147$, $F(1, 28) = 115.56$, $p < .001$, $\eta_p^2 = .805$. There was a marginally significant tendency toward an interaction between Interval and Block, $F(2, 56) = 2.46$, $p = .095$, $\eta_p^2 = .081$. However, the difference between short and long intervals attained significance in none of the blocks (Block 1, $t(28) = 1.07$, $p = .293$; Block 2, $t(28) = 1.61$, $p = .118$, Block 3: $t(28) = 1.06$, $p = .299$). None of the other interactions attained significance, all $F < 0.59$, all $p > .555$.

Error rates. We conducted an analogous ANOVA for error rates. The results were similar to the results with response times. Responses were significantly more correct for positive words, 2.88%, $SD = 2.04$, than for negative words, 4.60%, $SD = 2.17$, $F(1, 28) = 27.68$, $p < .001$, $\eta_p^2 = .497$. No other main effect, or interaction attained significance, all $F < 1.01$, all $p > .369$.

Post experimental interview. None of the participants reported any relation between interval duration and any aspect of the stimulus. This was also the case in the three following experiments, even though there was a strong correlation between duration and stimulus aspects in those experiments.

Discussion

We presented positive and negative words after short and long intervals without valence-interval correlation. We hypothesized a main effect for interval, a main effect for valence, and an interaction. The only hypothesis confirmed is the main effect for valence. As in previous studies with task-irrelevant stimulus valence, participants responded faster and more accurately to positive than to negative stimuli.

However, in contrast with previous studies with variable intervals, we did not observe performance advantages of the longer over the shorter interval. Either participants do not build up time expectancy in our paradigms or performance cannot benefit from the expectancy, because of the complexity of the task. Most previous studies on time expectancy employed simple symbol identification or detection tasks, requiring no linguistic evaluation of the word level (Los & Agter, 2005; Steinborn & Langner, 2011).

Most importantly, there was no interaction between interval and valence. Thus, we found no evidence for an a priori time-base valence expectancy. Hence, the time-base valence expectancy experimentally induced in the following experiment will not complement or counteract any preexisting time-based expectancy.

Experiment 2: Expecting Valence

The aim of this experiment was to investigate whether participants can form time-based expectancies for positive and negative stimulus valence. Interval was correlated with valence, and we tested whether performance was better with frequent, rather than infrequent, interval-valence combinations.

Method

Participants. Thirty subjects participated in the experiment. Their mean age was $M = 24.76$, $SD = 8.21$, range = [18, 53]. Four were left-handed, 26 right-handed. Twenty-three were female, seven were male.

Apparatus and stimuli. Apparatus and stimuli were the same as in Experiment 1 (i.e., words with the most extremely positive and negative valence).

Procedure. The procedure was the same as in Experiment 1, with one exception. One of the two intervals was paired more often with positive valence (80% of its occurrences), whereas the other was more often paired with negative valence (80% of its occurrences). Overall, both valences and both intervals were, again, presented equally often. The association between valence and interval was counterbalanced across participants. Participants were not informed about the time-based valence predictability before or

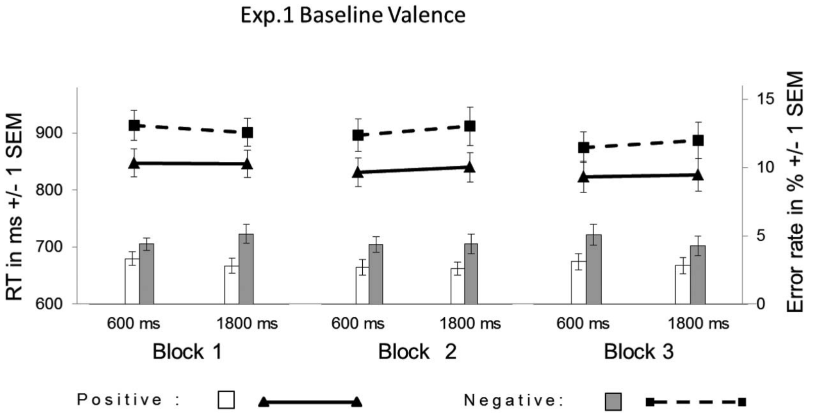

Figure 2. Mean response times and error rates per block in Experiment 1. Error bars represent ±1 standard error of the mean.

throughout the experiment. Half the participants learned to expect negative words after short intervals, and positive words after long intervals; in the other participants, this association was reversed.

Results

One participant was excluded because of an error score, 13%, more than 3.14 *SD*s ($SD = 3.02$) above the mean, $M = 3.51\%$.

Main analyses.

Response times. We conducted a 2 × 2 repeated measures ANOVA with the factors Valence (negative vs. positive) and Expectancy (expected vs. unexpected). Participants responded significantly faster to positive, 850 ms, $SD = 138$, than to negative words, 911 ms, $SD = 175$, $F(1, 28) = 32.65$, $p < .001$, $\eta_p^2 = .538$. Responses were also significantly faster when the valence was expected, 878 ms, $SD = 152$, than when it was not expected, 895 ms, $SD = 171$, $F(1, 28) = 5.30$, $p = .029$, $\eta_p^2 = .159$. The factors did not interact, $F(1, 28) = 0.03$, $p = .874$, $\eta_p^2 = .001$ (for mean values see Figure 3a).

Error rates. We conducted an analogous ANOVA with error rate as the dependent variable. The factor Valence was significant, $F(1, 28) = 7.06$, $p = .013$, $\eta_p^2 = .201$, with fewer errors for positive, 2.80%, $SD = 2.33$, than for negative words, 3.56%, $SD = 2.87$. Neither the effect for Expectancy, $F(1, 28) = 2.87$, $p = .102$, $\eta_p^2 = .093$, nor the interaction between both factors was significant, $F(1, 28) = 0.78$, $p = .385$, $\eta_p^2 = .027$ (Figure 3a).

Partitioning for typicality of activation. In the stimulus material, valence was strongly negatively correlated with activation, $r = -.69$, $p < .001$ (Figure 3d). Because of the overall limited size of the database, it was not possible to perfectly balance the data set with regard to arousal. Thus, any effects for valence could have been indirectly caused by activation. To control for this possibility, we partitioned the data into a set with atypical valence-activation combinations (e.g., low valence with low activation, see Figure 3e) and typical combinations (e.g., low valence and high activation, see Figure 3f). Stimuli with a valence rating lower than 0 (higher than 0, respectively), were considered as having low valence (high valence, respectively). Stimuli with an activation rating lower (higher, respectively) than the mean activation rating of all words ($M = 3.0196$), were considered as having low (high, respectively) activation.

Effects attributable to valence would predict replications of the main analysis in both subsets. Effects attributable to activation would predict replication only for the typical subset, but effects in the opposite direction for the atypical subset. As the subset with atypical combinations was very small (see Table 1, Row 2) we conducted error rate analyses only for typical combinations.

Atypical activation.

Response times. An ANOVA, with the factors Valence and Expectancy on response time, yielded a significant main effect for Valence, with faster response to positive, 866 ms, $SD = 141$, than to negative stimuli, 952 ms, $SD = 165$, $F(1, 28) = 19.56$, $p < .001$, $\eta_p^2 = .411$. The main effect for Expectancy was also significant, $F(1, 28) = 4.27$, $p = .048$, $\eta_p^2 = .132$, with shorter response latencies for expected valence, 886 ms, $SD = 143$, than for unexpected valence, 922 ms, $SD = 187$. The factors did not significantly interact, $F(1, 28) = 1.05$, $p = .315$, $\eta_p^2 = .036$ (Figure 3b).

Typical activation.

Response times. The main effect for Valence was again significant, $F(1, 28) = 29.15$, $p < .001$, $\eta_p^2 = .510$, with shorter response times for positive, 846 ms, $SD = 137$, than for negative words, 906 ms, $SD = 177$. A tendency toward shorter responses with expected, 876 ms, $SD = 155$, than with unexpected words, 889 ms, $SD = 172$, was marginally significant, $F(1, 28) = 3.44$, $p = .074$, $\eta_p^2 = .109$. The factors did not interact, $F(1, 28) = 0.18$, $p = .678$, $\eta_p^2 = .006$ (Figure 3c).

Error rates. In an analogous ANOVA for error rates, the factor Valence attained significance, $F(1, 28) = 7.50$, $p = .011$, $\eta_p^2 = .211$, attributable to fewer errors with positive, 2.74%, $SD = 2.42$, than with negative, 3.59%, $SD = 2.04$, words. Neither Expectancy, $F(1, 28) = 0.78$, $p = .383$, $\eta_p^2 = .027$, nor the interaction, $F(1, 28) = 0.31$, $p = .580$, $\eta_p^2 = .011$, attained significance (Figure 3c).

Partitioning for typicality of imageability. In the stimulus material, valence was strongly positively correlated with imageability, $r = .18$, $p < .001$ (Figure 3i). Thus, any effects for valence could have indirectly been caused by imageability. To control for this possibility, we partitioned the data into a set with atypical valence-imageability combinations (e.g., low valence with high imageability, see Figure 3j) and typical combinations (e.g., low valence and low imageability, see Figure 3k). Stimuli with an imageability rating lower (higher, respectively) than the mean imageability rating of all words ($M = 4.3304$), were considered as having low (high, respectively) imageability.

Effects attributable to valence would predict replications of the main analysis in both subsets. Effects attributable to imageability would predict replication only for the typical subset, but effects in the opposite direction for the atypical subset.

Atypical imageability.

Response times. In an ANOVA on response times using the subset with unusual valence-imageability parings, Valence attained significance, $F(1, 28) = 10.54$, $p = .003$, $\eta_p^2 = 273$, with faster responses to positive, 853 ms, $SD = 136$, than to negative, 882 ms, $SD = 160$, stimuli. However, the main effect for Expectancy was not significant, $F(1, 28) = 0.17$, $p = .686$, $\eta_p^2 = .273$. The interaction was also not significant, $F(1, 28) = 0.07$, $p = 797$, $\eta_p^2 = .002$ (Figure 3*g*).

Typical imageability.

Response times. Responses to positive words, 849 ms, $SD = 140$, were significantly faster than to negative words, 930 ms, $SD = 185$, $F(1, 28) = 34.15$, $p < .001$, $\eta_p^2 = .550$. Responses to expected valence, 886ms, $SD = 157$, were significantly faster than to unexpected valence, 911 ms, $SD = 188$, $F(1, 28) = 5.12$, $p = .032$, $\eta_p^2 = .155$. The factors did not interact, $F(1, 29) = 0.02$, $p = 892$, $\eta_p^2 = .001$ (Figure 3h).

Error rates. In an analogous ANOVA on error rates, the factor Valence was significant, $F(1, 28) = 5.81$, $p = .023$, $\eta_p^2 = .172$, with fewer errors for positive, 2.74%, $SD = 2.41$, than for negative words, 3.59%, $SD = 2.82$. There was a marginally significant tendency toward less correct responses with expected, 3.24%, $SD = 2.59$, than with unexpected valence, 2.99%, $SD = 2.46$, $F(1, 28) = 4.10$, $p = .053$, $\eta_p^2 = .128$. The factors did not interact, $F(1,$

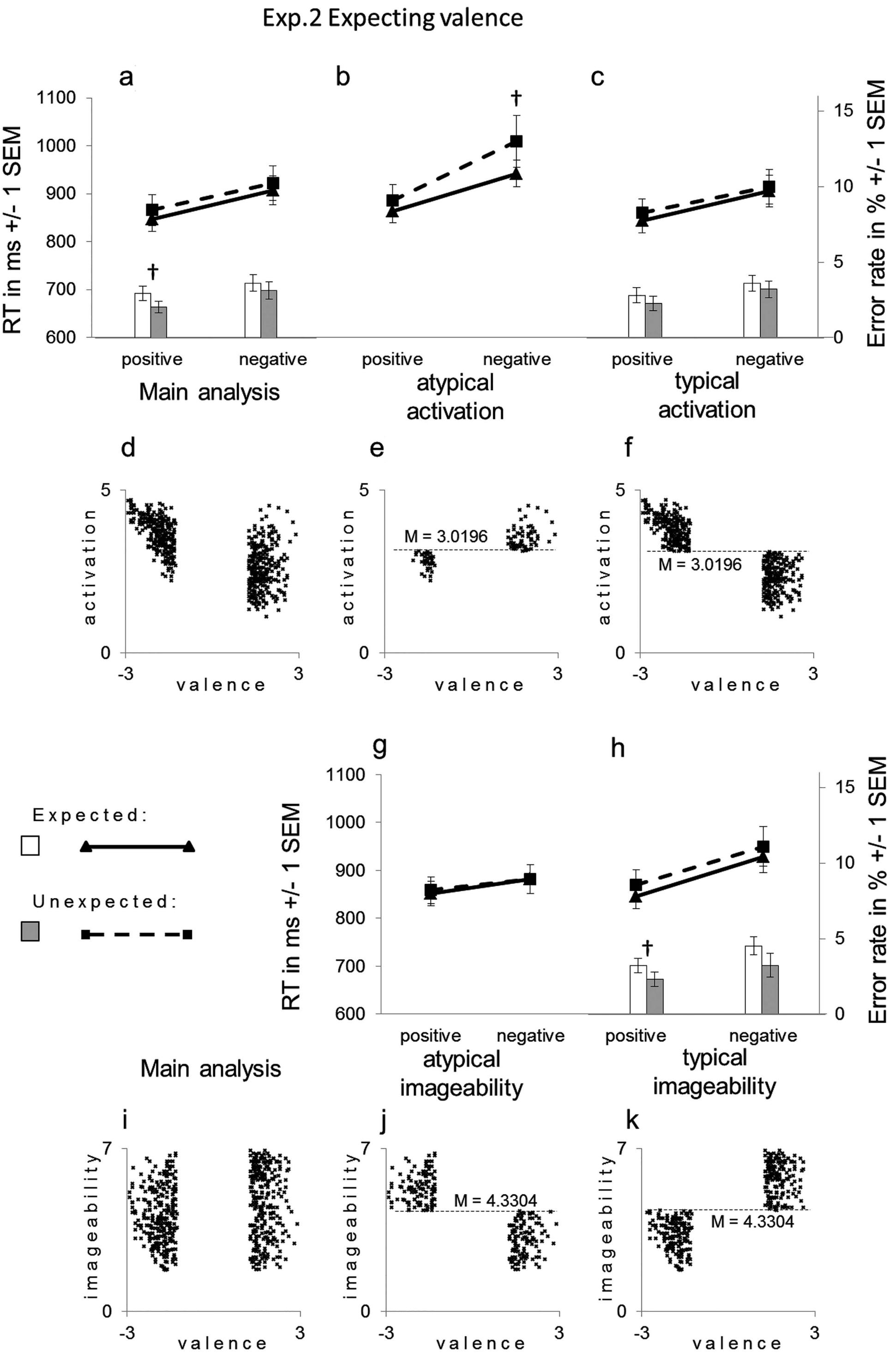

Figure 3. Mean response times and error rates in Experiment 2. Panels (d) to (f) illustrate the sets of stimulus words (as valence-activation combinations) analyzed in panels (a) to (c), respectively. Panels (i) to (k) illustrate the sets of stimulus words (as valence-imageability combinations) analyzed in panels (a), (g), and (h), respectively. A dagger above a couple of means represents marginal significance in a binary *t* test for that couple of means. Error bars represent ±1 standard error of the mean.

Table 1
Mean Activation and Imageability Ratings for Subsets of Data Analyzed for Experiment 2: Expected Valence

	Positive valence				Negative valence			
Stimulus set	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range
Activation rating								
All stimuli	300	2.56	0.68	[1.11, 4.50]	300	3.66	0.50	[2.12, 4.69]
Atypical activation	66	3.54	0.33	[3.11, 4.50]	40	2.81	0.23	[2.21, 3.11]
Typical activation	234	2.28	0.23	[2.21, 3.10]	260	3.79	0.39	[3.11, 4.69]
Imageability rating								
All stimuli	300	4.59	1.48	[1.78, 6.89]	300	4.06	1.78	[1.77, 6.78]
Atypical imageability	128	3.09	0.70	[1.78, 4.31]	117	5.30	0.63	[4.33, 6.78]
Typical imageability	172	5.71	0.71	[4.33, 6.89]	183	3.28	0.66	[1.77, 4.32]

28) = 0.26, p = 0612, η_p^2 = .009 (Figure 3h, and see Table 4 for a summary of results from Experiments 2 to 4).

Discussion

With regard to a general effect of irrelevant stimulus valence on response performance, we found a clear advantage for positive stimuli in response times and error rates, fully replicating the findings of Experiment 1.

In response times, we also found evidence for time-based expectancy of stimulus valence. The expectancy was not observed in error rates; this is in accordance with previous studies of time-based expectancy (Thomaschke & Dreisbach, 2013). Furthermore, the time-based expectancy was not modulated by whether the expected valence was positive or negative.

As valence was confounded with activation and imageability in the stimulus material, we reanalyzed the data in subsets with typical and atypical valence activation and valence-imageability combinations. With regard to activation, the results were clear. Responses were faster for temporally expected valence even in the subgroup with atypical activation. Time-based expectancy of activation would have predicted the opposite effect. Thus, we conclude that the overall time-based expectancy effect was attributable to valence expectancy, not to activation expectancy.

For the subgroup with atypical valence-imageability combinations the findings are less conclusive. There was neither a main effect for time-based valence expectancy, nor for time-based imageability expectancy. One potential explanation could be that this subset had, due to its small size, a too small statistical power to replicate the valence expectancy effect from the main analysis. Another explanation could be that valence expectancy was counteracted by imageability expectancy in this subset, and that these effects cancelled each other out, producing the Null effect. To test the latter hypotheses, we conducted a control experiment, testing whether participants could potentially form time-based imageability expectancies.

Experiment 3: Expecting Imageability

In Experiment 2, we observed a time-based expectancy effect for stimulus valence. However, more detailed analyses of the results showed that this valence-effect might have been complemented by a potential time-based expectancy effect for stimulus imageability. In this experiment we further investigate this possibility, by directly inducing time-based predictability of imageability and testing whether participants adapt to it by building time-based expectancies for imageability.

To this end, we replicated Experiment 2 using a highly similar stimulus set. However, in this experiment we manipulated the combinations of intervals with words in a way that time predicted primarily imageability instead of valence.

Method

Participants. Thirty subjects participated in the experiment. For one participant, no data were saved as a result of technical problems. Among the remaining 29 Participants 17 were female, and 2 were left-handed. The mean age was 24.14, SD = 3.64, range = [19, 31].

Apparatus and stimuli. The set of words was drawn from the same list of rated nouns as in Experiments 1 and 2. But this time, we selected the words with lowest (abstract) and with the highest (concrete) imageability. However, this experiment served as a control experiment for Experiment 2; thus, we wanted the stimulus material to largely overlap between both experiments Therefore, we required the words to be at least moderately valent, and consequently excluded neutral words (i.e., words with a valence rating between −1 and 1). The set of highly imaginable (concrete) stimuli was composed of the 150 female nouns with the highest imageability rating, M = 5.92, SD = 0.43, range = [5.14, 6.88], and the 150 male nouns with the highest imageability rating, M = 5.98, SD = 0.44, range = [5.23, 6.98], resulting in a set of 300 highly imaginable words, M = 5.95, SD = 0.43, range = [5.14, 6.89].

The set of minimally imaginable (abstract) stimuli was composed of the 150 female nouns with the lowest imageability ratings, M = 2.77, SD = 0.49, range = [1.56, 3.56], and the 150 most abstract male nouns, M = 2.99, SD = 0.54, range = [1.77, 3.78], resulting in a set of 300 highly abstract words, M = 2.88, SD = 0.53, range = [1.56, 3.78].

Procedure. The procedure was identical to Experiment 2, with the only exception that now imageability was temporally predictable. One of the two intervals was paired more often with low imageability (80% of its occurrences), whereas the other was more often paired with high imageability (80% of its occurrences).

Results

Main Analysis.

Response times. We conducted a 2 × 2 repeated measures ANOVA with the factors Imageability (concrete vs. abstract) and Expectancy (expected vs. unexpected). Participants responded significantly faster to concrete, 827 ms, $SD = 156$, than to abstract words, 887 ms, $SD = 175$, $F(1, 28) = 20.51$, $p < .001$, $\eta_p^2 = .423$. Participants responded numerically faster to words with expected imageability, 855 ms, $SD = 164$, than to words with unexpected imageability, 863 ms, $SD = 163$, but this tendency was not significant, $F(1, 28) = 1.45$, $p = .239$, $\eta_p^2 = .049$. Imageability and Expectancy did not interact, $F(1, 28) = 0.31$, $p = .584$, $\eta_p^2 = .011$ (Figure 4a).

Error rates. In an analogous ANOVA on error rates, Imageability was significant, $F(1, 28) = 14.16$, $p = .001$, $\eta_p^2 = .336$, with fewer errors for concrete, 2.80%, $SD = 1.31$, than for abstract words, 3.94%, $SD = 1.50$. Expectancy was also significant, $F(1, 28) = 5.86$, $p = .022$, $\eta_p^2 = .173$, with a higher error rate for words with expected imageability, 3.47%, $SD = 1.34$, than with unexpected imageability, 2.80%, $SD = 1.54$. The interaction between Imageability and Expectancy was not significant, $F(1, 28) = 0.89$, $p = .354$, $\eta_p^2 = .031$ (Figure 4a).

Partitioning for typicality of valence. As in Experiment 2, imageability was strongly positively correlated with valence, $r = 2.40$, $p < .001$ (Table 2 and Figure 4d). To disentangle any effects from imageability and valence, we reanalyzed the data in two subsets containing atypical (e.g., low imageability with positive valence, see Figure 4e), and typical (e.g., low imageability with negative valence, see Figure 4f) combinations.

Atypical valence.

Response times. The factor Imageability was significant with faster responses to concrete, 836 ms, $SD = 157$, than to abstract words, 862 ms, $SD = 172$, $F(1, 28) = 8.08$, $p = .008$, $\eta_p^2 = .224$. Expectancy was not significant, $F(1, 28) = 0.07$, $p = 940$, $\eta_p^2 < .001$. The interaction was also not significant, $F(1, 28) = 2.21$, $p = .148$, $\eta_p^2 = .073$ (Figure 4b).

Typical valence.

Response times. Imageability was again significant, $F(1, 28) = 23.06$, $p < .001$, $\eta_p^2 = .452$, with faster responses to concrete, 823 ms, $SD = 156$, than to abstract words, 909 ms, $SD = 180$. Expectancy, $F(1, 28) = 0.69$, $p = .414$, $\eta_p^2 = .024$, as well as the interaction, $F(1, 28) = 1.63$, $p = .213$, $\eta_p^2 = .055$, was not significant (Figure 4c).

Error rates. Participants committed significantly fewer errors with concrete, 2.57%, $SD = 1.42$, than with abstract words, 4.72%, $SD = 2.26$, $F(1, 28) = 17.59$, $p < .001$, $\eta_p^2 = .386$. However, responses for words with expected imageability, 3.60%, $SD = 1.58$, were less correct than to those with unexpected imageability, 2.74%, $SD = 1.93$, $F(1, 28) = 4.96$, $p = .034$, $\eta_p^2 = .150$. The factors did not significantly interact, $F(1, 28) = 0.50$, $p = .488$, $\eta_p^2 = .017$ (Figure 4c).

Partitioning for typicality of activation. Imageability was negatively correlated with activation, $r = -.234$, $p < .001$ (Figure 4i). Following the same logic as with valence as a potential confound, we split the data into subsets with atypical (e.g., low imageability with low activation, see Figure 4j), and with typical (e.g., low imageability with high activation, see Figure 4k) combinations of imageability and activation.

Atypical activation.

Response times. Responses to concrete words, 842, ms, $SD = 160$, were significantly faster than to abstract words, 871 ms, $SD = 169$, $F(1, 28) = 4.40$, $p = .045$, $\eta_p^2 = .136$. The factor Expectancy, $F(1, 28) = 1.39$, $p = .249$, $\eta_p^2 = .047$, and Interaction, $F(1, 28) = 0.42$, $p = .521$, $\eta_p^2 = .015$, were not significant (Figure 4g).

Typical activation.

Response times. Again, only the factor Imageability was significant, $F(1, 28) = 35.38$, $p < .001$, $\eta_p^2 = .558$, with faster responses to concrete, 817 ms, $SD = 154$, than to abstract words, 897 ms, $SD = 180$. Expectancy, $F(1, 28) = 0.39$, $p = .540$, $\eta_p^2 = .014$, and the interaction, $F(1, 28) = 1.479$, $p = .23$, $\eta_p^2 = .050$, were not significant (Figure 4h).

Error rates. Errors were significantly fewer for concrete words, 2.42%, $SD = 1.32$, than for abstract words, 4.31%, $SD = 1.88$, $F(1, 28) = 31.15$, $p < .001$, $\eta_p^2 = 527$. Again, responses with expected imageability, 3.47%, $SD = 1.51$, were significantly less correct than with unexpected imageability, 2.72%, $SD = 2.03$, $F(1, 28) = 6.03$, $p = .021$, $\eta_p^2 = .177$. The interaction was not significant, $F(1, 28) = 2.34$, $p = .137$, $\eta_p^2 = .077$ (Figure 4h).

Inter-experiment comparison. The factor Expectancy was, in response times, significant in Experiment 2, where valence was expected, but not significant in Experiment 3, where imageability was expected. To further confirm this pattern, an mixed 2 × 2 × 2 ANOVA with the factors Experiment (Exp. 2 vs. Exp.3), Word-Type (positive/concrete vs. negative/abstract), and Expectancy (expected vs. unexpected) was conducted. However, the interaction between Experiment and Expectancy was not significant, $F(1, 56) = 0.85$, $p = 360$, $\eta_p^2 = 0.15$.

Discussion

The task-irrelevant imageability level of a word affected word processing. Error rates and response times were lower for concrete than for abstract words.

However, time-based expectancy for imageability did not significantly affect response times, irrespective of whether valence or activation was atypical or typical. This means that any potential effect of imageability does not manifest in response latency. We conclude from this result that the time-based valence expectancy in Experiment 2 was not even partly attributable to time-based imageability expectancy. Note, however, that an absence of expectancy in Experiment 3 has not been confirmed by an Interexperiment comparison with Experiment 2.

Concerning error rates, we observed an unpredicted negative effect of imageability expectancy. Error rates were higher with temporally expected than with unexpected imageability. One might speculate that this effect was related to the valence expectancy effect in Experiment 2, in the sense of a speed–accuracy trade-off: time-based expectancy made responses faster at the cost of accuracy. To test whether there was a systematic relation between speed and accuracy, we conducted a correlation analysis for the mean response time and the mean accuracy for each participant in Experiments 2 to 4 (see Figure 6). We found no significant correlation in any of the experiments. Thus, we conclude that the expectancy effect in error rates for imageability in

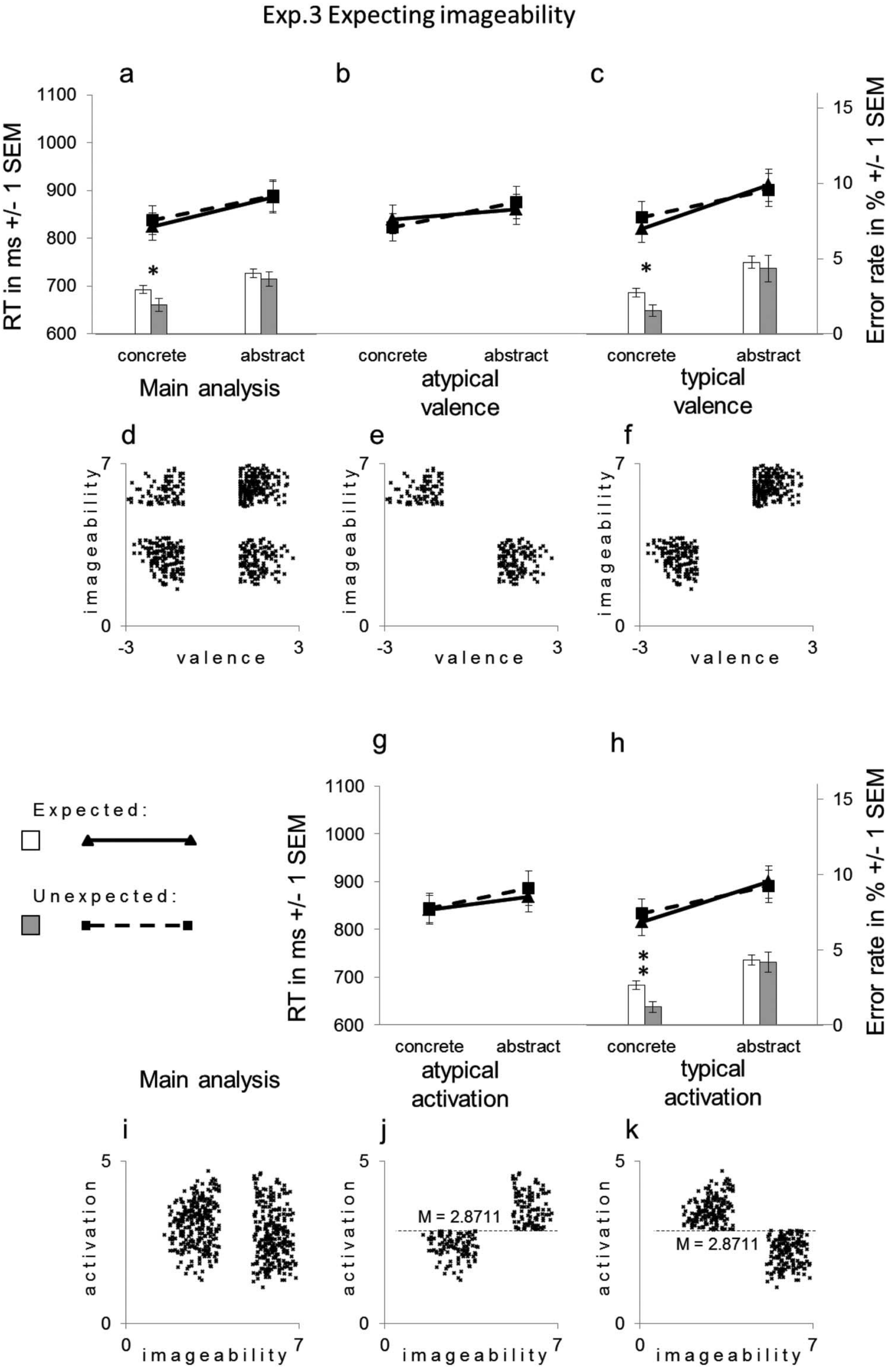

Figure 4. Mean response times and error rates in Experiment 3. Panels (d) to (f) illustrate the sets of stimulus words (as valence-imageability combinations) analyzed in panels (a) to (c), respectively. Panels (i) to (k) illustrate the sets of stimulus words (as activation-imageability combinations) analyzed in panels (a), (g), and (h), respectively. An asterisk above a couple of means represents significance at the .05 level in a binary *t* test for that couple of means. Two asterisks represent significance at the .01 level. Error bars represent ±1 standard error of the mean.

Table 2
Mean Valence and Activation Ratings for Subsets of Data Analyzed for Experiment 3: Expected Imageability

	Concrete				Abstract			
Stimulus set	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range
				Valence rating				
All stimuli	300	.62	1.46	[−2.90, 2.60]	300	−.14	1.65	[−2.70, 2.80]
Atypical valence	82	−1.66	0.50	[−2.90, −1.00]	140	1.56	0.41	[1.00, 2.80]
Typical valence	218	1.45	0.40	[1.00, 2.60]	160	−1.64	0.40	[−2.70, −1.00]
				Activation rating				
All stimuli	300	2.68	1.46	[1.11, 4.62]	300	3.06	0.67	[1.32, 4.69]
Atypical activation	113	3.54	0.49	[2.88, 4.62]	114	2.34	0.35	[1.32, 2.83]
Typical activation	187	2.17	0.43	[1.11, 2.86]	186	3.50	0.39	[2.88, 4.69]

Experiment 3 was unrelated to the expectancy effect in response times for valence in Experiment 2.

Experiment 4: Expecting Activation

In Experiments 2 and 3, we have demonstrated that stimulus valence can be expected based on time intervals, and that this valence expectancy is not an artifact of activation or imageability. However, Kuperman et al. (2014) have shown that valence and activation impact independently on word processing. In this experiment we investigate whether affective time-based expectancy is restricted to the affective dimension of valence, or whether activation can also be expected in a time-based manner.

The experiment mirrors Experiment 2, with two exceptions. First, we present only words with extremely low or high activation levels and, second, interval duration predicts activation level instead of valence.

Method

Participants. Thirty subjects participated in the study. Seven were left-handed, 19 were female. Their mean age was 25.26, $SD = 7.99$, range = [18, 52].

Apparatus and stimuli. We included the male and female nouns with the most extreme low and high activation ratings. In contrast to Experiment 3, this was not a direct control for Experiment 2. Consequently, we did not attempt to keep the stimulus material similar, and also allowed valence-neutral words. The set of low activating stimuli was composed of the 150 female nouns with the lowest activation rating, $M = 1.80$, $SD = 0.19$, range = [1.28, 2.06], and the 150 male nouns with the lowest activation rating, $M = 1.87$, $SD = 0.20$, range = [1.11, 2.14], resulting in a set of 300 low activating words, $M = 1.84$, $SD = 0.20$, range = [1.11, 2.14].

The set of highly activating stimuli was composed of the 150 female nouns with the highest activation ratings, $M = 3.87$, $SD = 0.31$, range = [3.44, 4.69], and the 150 male nouns with the highest activation rating, $M = 3.92$, $SD = 0.28$, range = [3.52, 4.67], resulting in a set of 300 highly activating words, $M = 3.90$, $SD = 0.29$, range = [3.44, 4.69].

Procedure. The procedure was identical to Experiments 2 and 3, with the only exception that activation was now temporally predictable. One of the two intervals was paired more often with low activation (80% of its occurrences), while the other was more often paired with high activation (80% of its occurrences). The association between interval and activation was counterbalanced across participants.

Results

One participant was excluded because of an error score, 49.3%, more than 5.09 *SD*s ($SD = 8.68$) above the mean, 5.05%.

Main analysis.

Response times. We conducted a 2 × 2 repeated measures ANOVA with the factors Activation (low vs. high) and Expectancy (expected vs. unexpected). Participants responded significantly faster to lowly, 947 ms, $SD = 222$, than to highly activating words, 967 ms, $SD = 239$, $F(1, 28) = 6.54$, $p = .016$, $\eta_p^2 = .189$. Responses were significantly faster when the activation level was expected, 953 ms, $SD = 229$, than when it was not expected, 976 ms, $SD = 231$, $F(1, 28) = 4.62$, $p = .040$, $\eta_p^2 = .142$. Activation did not interact with Expectancy, $F(1, 28) = 1.87$, $p = .182$, $\eta_p^2 = .063$ (Figure 5a).

Error rates. In an analogous ANOVA on error rates, Activation was significant, $F(1, 28) = 5.09$, $p = .032$, $\eta_p^2 = .154$, with less error prone responses for minimally activating words, 3.34%, $SD = 2.37$, than for highly activating words, 3.71%, $SD = 2.66$. Expectancy was not significant, $F(1, 28) = 0.29$, $p = .587$, $\eta_p^2 = .010$. The interaction between Activation and Expectancy did not attain significance, $F(1, 28) = 2.78$, $p = .107$, $\eta_p^2 = .090$ (Figure 5a). For a statistics summary of Experiments 2 to 4 see Table 4.

Partitioning for typicality of valence. Activation was, as in Experiment 2, highly negatively correlated with valence, $r = -.702$, $p < .001$ (see Figure 5d). To control for confounds between activation and valence, we conducted separate analyses for atypical and for typical combinations of activation and valence (Figures 5e and 5f).

Atypical valence.

Response times. The factor Activation was, in this subset of words, not significant, $F(1, 28) = 0.92$, $p = .345$, $\eta_p^2 = .032$. However, with regard to Expectancy, there was a marginally significant tendency toward faster responses to words with expected, 964 ms, $SD = 230$, than unexpected activation, 1002 ms, $SD = 260$, $F(1, 28) = 3.51$, $p = .072$, $\eta_p^2 = .111$. The interaction

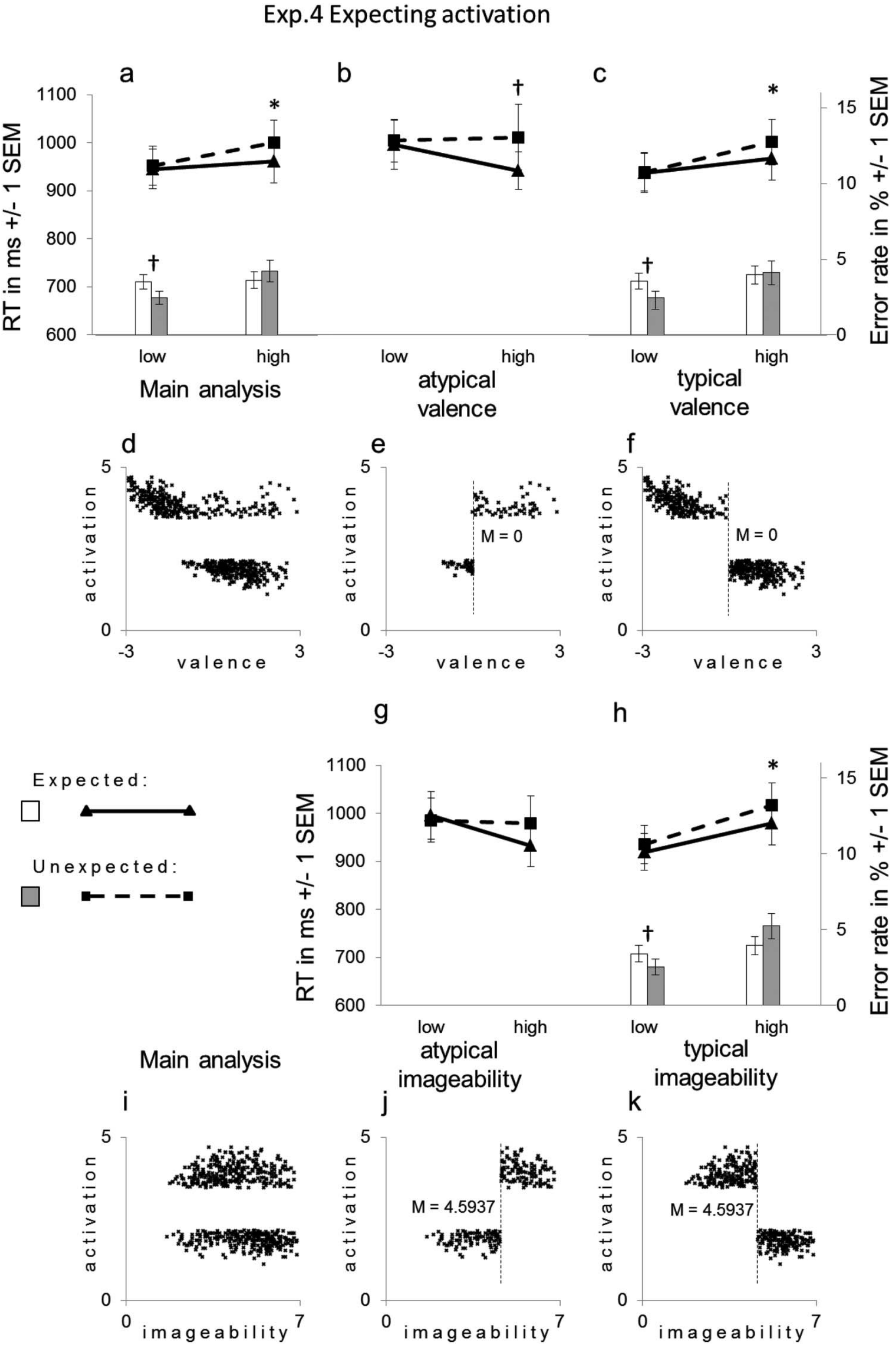

Figure 5. Mean response times and error rates in Experiment 4. Panels (d) to (f) illustrate the sets of stimulus words (as valence-activation combinations) analyzed in panels (a) to (c), respectively. Panels (i) to (k) illustrate the sets of stimulus words (as activation-imageability combinations) analyzed in panels (a), (g), and (h), respectively. An asterisk above a couple of means represents significance at the .05 level in a binary *t* test for that couple of means. A dagger represents marginal significance. Error bars represent ±1 standard error of the mean.

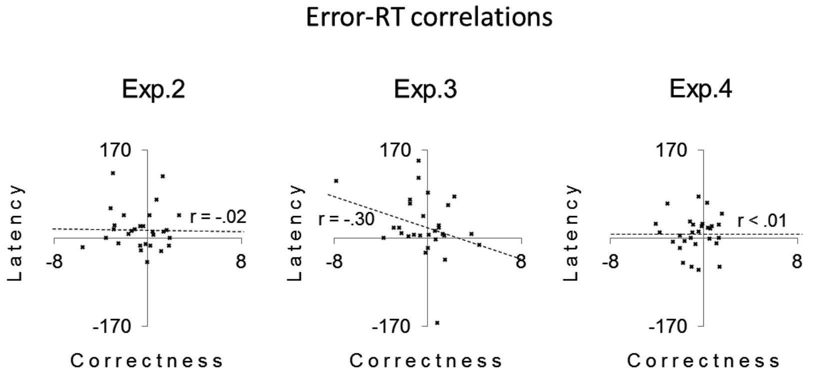

Figure 6. Correlations between error rates (correctness) and mean response time (latency) in Experiments 2 to 4. Individual means are plotted as deviations from their grand mean. Dotted lines represent regression lines. *r* is the regression coefficient.

was not significant, $F(1, 28) = 1.00$, $p = .327$, $\eta_p^2 = .034$ (Figure 5b).

Typical valence.

Response times. In this subset of data, the factor activation was significant, $F(1, 28) = 11.73$, $p = .002$, $\eta_p^2 = .295$, with faster responses to words with low, 936 ms, $SD = 215$, than with high activation levels, 972 ms, $SD = 246$. However, the factor Expectancy was not significant, $F(1, 28) = 2.77$, $p = .108$, $\eta_p^2 = .090$. The interaction was also not significant, $F(1, 28) = 2.07$, $p = .161$, $\eta_p^2 = .069$ (Figure 5c).

Error rates. There were significantly fewer errors with minimally activating, 3.40%, $SD = 2.39$, than with highly activating words, 3.99%, $SD = 2.98$, $F(1, 28) = 5.66$, $p = .024$, $\eta_p^2 = .168$. The factor Expectancy, $F(1, 28) = 0.87$, $p = .360$, $\eta_p^2 = .030$, and the interaction, $F(1, 28) = 1.47$, $p = .235$, $\eta_p^2 = .505$, were not significant (Figure 5c and Table 3).

Partitioning for typicality of imageability. Activation was, as in Experiment 3, negatively correlated with imageability, $r = -.241$, $p < .001$ (see Figure 5i). Consequently we conducted separate analyses for atypical and for typical activation imageability combinations (Figures 5j and 5k).

Atypical imageability.

Response times. There was a main effect for activation, $F(1, 28) = 7.57$, $p = .010$, $\eta_p^2 = .213$, with faster responses to words with low, 995 ms, $SD = 256$, than high, 940 ms, $SD = 235$, activation levels. The effect of Expectancy was not significant, $F(1, 28) = 0.66$, $p = .422$, $\eta_p^2 = .023$. The factors did not significantly interact, $F(1, 28) = 3.55$, $p = .070$, $\eta_p^2 = .112$ (Figure 5*g*).

Typical imageability.

Response times. Also in this subset of the data, responses to minimally activating words, 921 ms, $SD = 204$, were significantly faster than to highly activating words, 984 ms, $SD = 244$, $F(1, 28) = 17.75$, $p < .001$, $\eta_p^2 = .388$. Responses to words with expected activation, 948, ms, $SD = 221$, were significantly faster than responses to words with unexpected activation, 972 ms, $SD = 220$, $F(1, 28) = 7.33$, $p = .011$, $\eta_p^2 = .207$. The factors did not interact, $F(1, 28) = 0.65$, $p = .426$, $\eta_p^2 = .023$.

Error rates. The factor activation attained significance, $F(1, 28) = 8.60$, $p = .007$, $\eta_p^2 = .235$, as a result of more correct responses for minimally activating words, 3,25%, $SD = 2.83$, than for highly activating words, 4.13%, $SD = 2.87$. The factor Expectancy was, however, not significant, $F(1, 28) = 0.16$, $p = .697$, $\eta_p^2 = .005$. There was a marginal tendency toward an interaction between the factors, $F(1, 28) = 3.79$, $p = .062$, $\eta_p^2 = .119$. Responses to words with expected low activation, 3.38%, $SD = 2.98$, were more error prone than responses to words with unexpected low activation, 2.52%, $SD = 3.26$, but responses to expected high activation, 3.93%, $SD = 3.29$, were less error prone than responses to words with unexpected high activation, 5.20%, $SD = 4.46$.

Table 3
Mean Valence and Imageability Ratings for Subsets of Data Analyzed for Experiment 4: Expected Activation

	Low activation				High activation			
Stimulus set	*N*	*M*	*SD*	Range	*N*	*M*	*SD*	Range
Valence rating								
All stimuli	300	0.78	0.75	[−1.00, 2.56]	300	−1.12	1.37	[−2.90, 2.90]
Atypical valence	50	−0.30	0.31	[−1.00, .00]	59	1.28	0.82	[.00, 2.90]
Typical valence	250	0.99	0.61	[.03, 2.56]	241	−1.71	0.63	[−2.90, −1.00]
Imageability rating								
All stimuli	300	4.91	1.21	[1.65, 6.89]	300	4.28	1.16	[1.77, 6.78]
Atypical imageability	106	3.51	0.76	[1.65, 4.59]	110	5.54	0.60	[4.64, 6.78]
Typical imageability	194	5.67	0.55	[4.64, 6.89]	190	3.55	0.68	[177, 4.59]

Table 4
ANOVA Statistics for Main Analyses in Experiments 2 to 4

	Response times			Error rates		
Experiment	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Experiment 2: Expected valence						
Valence	32.64	.000	.538	7.06	.013	.201
Expectancy	5.29	.029	.159	2.86	.102	.093
Valence × Expectancy	.02	.874	.001	.77	.385	.027
Experiment 3: Expected imageability						
Imageability	20.50	<.001	.423	14.16	.001	.336
Expectancy	1.45	.239	.049	5.86	.022	.173
Imageability × Expectancy	.30	.584	.011	.88	.354	.031
Experiment 4: Expected activation						
Activation	6.53	.016	.189	5.08	.032	.154
Expectancy	4.62	.040	.142	.28	.597	.010
Activation × Expectancy	1.87	.182	.063	2.78	.107	.090

Discussion

We tested whether the task-irrelevant activation level of a stimulus can be expected in a time-based manner. We observed a clear time-based expectancy effect for activation level. This time-based expectancy effect cannot be interpreted as an artifact from time-based valence expectancy because, even for atypical valence-activation combinations, performance for expected activation was superior to performance for expected valence. Thus the time-based expectancy for activation is independent of the time-based expectancy for valence, as observed in Experiment 2. For an overview of Experiments 2 to 4 see Table 5.

Concerning the overall (expectancy-independent) impact of activation on word processing, our findings perfectly replicate Kuperman et al.'s (2014) study confirming that activation has an independent, but slightly smaller effect on word processing than has valence.

General Discussion

Summary of Findings

In four experiments, we demonstrated that specific affect can be expected based merely on the flow of time. Participants were asked to classify the grammatical gender of target words that appeared after warning intervals of different durations. We manipulated the correlation between interval duration and word affect. The first experiment—with temporally noncorrelated affect—confirmed that there is no strong general a priori association between time and affect.

Such an association can, however, quickly be acquired when affect is temporally predictable: in Experiment 2, participants learned to expect either the positive or the negative valence of a word, depending only on whether the word appears early or late.

Table 5
Summary of Results From Experiments 2 to 4

	Main analysis		Atypical activation	Typical activation		Atypical imageability	Typical imageability	
Difference	RT	Error	RT	RT	Error	RT	RT	Error
Experiment 2: Expected valence								
Negative − Positive	60^{***}	$.76^{*}$	86^{***}	60^{***}	$.85^{*}$	29^{**}	81^{***}	1.25^{*}
Unexpected − Expected	17^{*}	−.61	37^{*}	13†	−.26	3	25^{*}	$-2.84^{\dagger}$

	Main analysis		Atypical valence	Typical valence		Atypical activation	Typical activation	
	RT	Error	RT	RT	Error	RT	RT	Error
Experiment 3: Expected imageability								
Abstract − Concrete	60^{***}	1.14^{**}	26^{**}	86^{***}	2.15^{***}	29^{*}	80^{***}	1.89^{***}
Unexpected − Expected	8	$-.67^{*}$	3	10	$-.86^{*}$	11	5	$-.74^{*}$

	Main analysis		Atypical valence	Typical valence		Atypical imageability	Typical imageability	
	RT	Error	RT	RT	Error	RT	RT	Error
Experiment 4: Expected activation								
High − Low	20^{*}	$.37^{*}$	−49	36^{**}	$.59^{*}$	-56^{*}	63^{***}	$.88^{**}$
Unexpected − Expected	22^{*}	−.23	38†	18	−.47	23	21^{*}	.24

Importantly, the valence was irrelevant to the task in all our experiments. Although participants' behavior strongly adapted to the temporal predictability of affect, none of the participants became aware of the predictability pattern.

In a third experiment, we verified that this implicit time-based expectancy does not occur for nonaffective stimulus aspects, such as the imageability of target words. In the last experiment, we demonstrated that time-based expectancy can, next to valence, also be built for activation, another dimension of affect. By additional analyses of Experiments 2 and 4, we were able to show that neither expectancy for valence can be reduced to expectancy of activation, nor vice versa. We conclude that humans can form implicit time-based affect expectancies in a way that is specific for the two affect dimensions, valence and activation.

Our findings show that, when affectively stimulating environments are temporally structured in a predictable way, these temporal structures systematically and reliably shape behavior, without individuals explicitly attending to affect, and without individuals being aware of these temporal structures. For our initial example, this suggests that an Internet search can be performed better when irrelevant emotional adverts pop up in a temporally predictable way.

Relation to Previous Research

Our findings extend the domain of time-based expectancy to the affective domain. It was previously thought that time-based expectancy mainly supports response-related processing stages. The current state of knowledge is that processing of stimulus features can only benefit from time-based expectancy when these features are directly relevant for identifying the correct response (Thomaschke et al., 2016), but not when they are completely response-irrelevant (Thomaschke, Kiesel, & Hoffmann, 2011). With regard to nonaffective stimulus features, this view has been confirmed by the present study (Experiment 3). Imageability might be a feature of a stimulus word that is response relevant in a general nonspecific sense: the referents of concrete words are more likely to afford direct physical actions than the referents of abstract words. However, in the context of our experiment, imageability was irrelevant for determining the correct response to the target word. Consequently, we observed, in line with previous theorizing, no time-based expectancy for the stimulus feature imageability.

Yet, extending previous knowledge, we demonstrated—for the first time—that processing of response-irrelevant stimulus features can indeed benefit from time-based expectancy, given that the features elicit affective processing. Thus, time-based expectancy facilitates not only motor-related processing, but also affective processing.

The findings also open the possibility of reinterpreting previous findings. Wendt and Kiesel (2011) have shown that time-based expectancy can also be formed for response conflict (see Introduction). In their study, interval duration predicted whether distractors accompanying the target will be target-congruent or target-incongruent. Performance was better with expected than with unexpected congruence (or incongruence, respectively). Yet, several recent lines of evidence have suggested that response conflict is perceived as negative; thereby suggesting that conflict processing can, in a large part, be conceived as valence processing (Dreisbach & Fischer, 2012a, 2015, 2016; Fritz & Dreisbach, 2013). One might speculate that Wendt and Kiesel's (2011) findings of time-based conflict expectancy were actually instances of time-based valence expectancy. Time-based expectancy might have facilitated processing of the affective values associated with conflict: positive valence for congruence, and negative valence for incongruence. Such an explanation would embed Wendt and Kiesel's finding in a more unified theoretical framework of time-based affect expectancy.

Although our findings are in line with previous time-based expectancy research, in that expectancy facilitates processing, they are in contrast to previous theories about affect expectancy. Kleinsorge (2007, 2009) demonstrated the detrimental effects of expected valence and activation on task performance, whereas we observed performance improvements by valence and activation expectancy.

This contrast might indicate that explicit color cues are counterproductive, while implicit temporal cues are beneficial for affective processing. However, we rather propose that the contrast in findings is grounded in another, more fundamental, difference between Kleinsorge's and our studies: the integration of affective information into the relevant target. In Kleinsorge's study, the affective pictures were not an inherent part of the target; instead, they were in the background of the relevant mathematical equations. Thus, they can be seen as distractor stimuli accompanying the target stimulus. In our study, on the contrary, the affective information was an inherent property of the target word itself.

This contrast in effect direction between cueing irrelevant target features and irrelevant distractor features is well established in the nonaffective domain. Cueing irrelevant target features improves cognitive processing (Posner, 1980), while cueing irrelevant distractor features impairs cognitive processing (Moher & Egeth, 2012). Our findings suggest that this difference in effect direction also holds when the predicted irrelevant features are affective features, such as valence or activation.

Theoretical Explanations

Our findings fit well into our model of time-based expectancy described in the Introduction (Thomaschke & Dreisbach, 2013). At presentation of the fixation cross, participants run through a cascade of mental time-representation; whenever a target is presented, connections from the just passed time-representations to expectancy generating neural populations for that target are strengthened.

However, this leaves open the question, which are those expectancy generating neural populations? Which cognitive mechanism can prepare processing of a certain irrelevant stimulus valence (or activation, respectively) in a way that responses to targets become faster? How can prior affect information improve performance, when affect is task-irrelevant? We propose three different possibilities, all rooted in previous research.

Compensating affect-perception interference. One possible explanation draws on automatic preemptive compensation of emotion-cognition interferences. Irrelevant—particularly negative—valence information is well known to interfere with cognitive tasks. Valence in visual stimuli is detected quite rapidly by projections to the amygdala, with the effect that the amygdala projects back into the visual system within the first 60 to 90 ms after stimulus occurrence (Stolarova, Keil, & Moratti, 2006). The projections from the amygdala to the visual cortex are magnocellular. Bocanegra and Zeelenberg (2009) and Becker (2012) suggested that these magnocellular projections shift the balance in the visual system from ventral to dorsal processing, because the dorsal visual pathway has primarily magnocellular input, while the ventral path relies on parvocellular input (Maunsell, Nealey, & DePriest, 1990). This serves behavioral motivational functions, because the dorsal pathway translates valence into automatic approach—or avoidance—responses. However, conscious task-rule guided behavior—such as the gender classification in our task—requires processing in the ventral visual pathway. Consequently, conscious rule-based processing is slowed down for affective—especially negative—pictures (Becker, 2012; Maljkovic & Martini, 2005).

We assume that time-based expectancy results in a temporally specific preemptive activation of the ventral pathway to counteract its anticipated deficit. After learning of the time-affect correlation, whenever a negative stimulus is expected to occur in the immediate future, excitatory projections from the currently active time representation activate exactly those parts of the ventral processing system that would suffer the most from the expected balance shifts to dorsal processing due to negative stimulus valence. At the other interval duration, the same would happen—to a lesser degree—for positive valence.

Note that such expectancies are likely to work without participants being aware of it. In the nontemporal domain, for example, Moratti and Keil (2009) showed that for fear conditioning, a conditioned stimulus can modulate the visual cortex in an anticipative manner without participants consciously expecting a fearful stimulus. However, this explanation has the disadvantage that it would predict a stronger benefit of time-based expectancy for negative than for positive valence—a nonsignificant interaction in our study.

Priming semantic networks. Another potential explanation draws on semantic network theory. It is widely assumed in cognitive psychology that concepts are represented in semantic networks (Collins & Loftus, 1975). By these networks, they are connected to representations of all their features, including the words denoting them. When one feature is activated, activation spreads through the network, to the effect that all features connected to it are also activated to a degree. Thus, preactivation of a feature supports processing each concept—and its respective word—connected to that feature. This is the standard explanation for semantic priming (Neely, 1991).

We propose that when one expects after a certain interval duration positive valence, it means that one is preactivating the feature “positive” shortly before expiration of this interval. This in turn preactivates via semantic networks every concept it is connected to, including representations of the words for these concepts. Consequently, at this point, processing of every positive word is facilitated. Thus, when gender discrimination has to operate on positive words, it is facilitated at this point, because the positive word is preactivated. The same would hold for negative words after the other interval.

Compensating affect-motor interference. A third potential explanation of the observed adaptation effect draws on the motivational value of affective stimulation. Affective stimulus features—task-relevant or not—automatically activate motor responses. Positive stimuli evoke approach responses and negative stimuli evoke avoidance responses (Chen & Bargh, 1999). Among these responses are also hand movements toward or away from the own body (Seibt, Neumann, Nussinson, & Strack, 2008).

This means that stimulus affect in our experiments induced task-irrelevant covert motor activation for approach, or avoidance movements. Such movement tendencies interfere with the actual responses to the nonaffective gender classification task. However, anticipating affect in a time-based manner might have allowed participants to preemptively attenuate motivational tendencies associated with the anticipated affect. This would have reduced interference, and thus facilitated the actual response, when stimulus affect matched the expected one. This third explanation is similar to the first, just differing in the locus of the preemptive compensation of affective interference. The first explanation locates the compensative mechanisms in the perceptual system, while this locates it in the motor system.

The present data do not allow any conclusions concerning these explanations; further studies might be able to distinguish between them.

Practical Implications

Our findings have important implications for language processing as well as for human-computer interaction.

Language processing. As reviewed in the Introduction, conversation partners develop various types of time-based expectancies during verbal communication (MacGregor, Corley, & Donaldson, 2010; Watanabe, Hirose, Den, & Minematsu, 2008), and also valence expectancies (Roberts & Francis, 2013; Roberts et al., 2011; Roberts & Norris, 2016). Thus, speakers are highly sensitive to the temporal delay structure of speech.

When communication is computer-based, however, such as in voicemail or video conferences, it is commonly interspersed with short technically caused delays due to limitations in data transmission. These artificial delays distort the natural temporal structure of speech, and various psychological side effects arise (e.g., Olbertz-Siitonen, 2015; Schoenenberg, Raake, Egger, & Schatz, 2014), partly because the delay is misattributed to conversation partners, affecting those partners’ perceived competence and likability (Schoenenberg, Raake, & Koeppe, 2014).

Importantly for the present context, artificial transmission delays also distort the characteristic time-affect correlational pattern of conversions, and thereby cause violations in time-based affect expectancy. Our study demonstrates the potential consequences of such distortions: we have shown that the temporal affect predictability facilitates the processing of nonaffective content. Thus, the consequences of artificial delays go beyond obvious confusions about the perceived speech’s affective tone of voice. Instead, processing of even the communication’s nonaffective content is impaired by violated affect expectancy. This suggests that disturbing the temporal-valence structure of communication has direct and profound effects on cognitive understanding.

Thus, our findings are relevant to the current public debates concerning net neutrality (Greenstein, Peitz, & Valletti, 2016; Lee & Shin, 2016), because they show that the effects of data transmission delay in communication go far beyond lost time by longer waiting (Shin, 2016), but also affect the understanding of the transmitted content. This is especially the case for affectively charged content, such as human verbal communication. However, our study can, of course, only be a starting point for investigating the effects of distorted time-affect patterns on communication. A reliable estimation of such distortions' effects would require an analysis of the overall performance decrements in realistic communication settings with systematically manipulated delays, using, for example, paradigms such as that employed by Roberts and colleagues (Roberts & Francis, 2013; Roberts et al., 2011; Roberts & Norris, 2016).

Human–computer interaction. Our interactions with the environment become increasingly mediated by technology (Livingstone, 2009), and are hence affected by technological delays (Dabrowski & Munson, 2011). As most everyday life computing resources rely on heavily parallel processing, system delay must actively be scheduled across users and processes (Weber, Haering, & Thomaschke, 2013). A recent study by Thomaschke and Haering (2014) demonstrated that time-based expectancy can be successfully employed to inform delay scheduling algorithms. Timing scenarios with deterministic informative delay durations improved user performance in a simple classification task. However, in that study, system delays predicted only nonaffective aspects of the upcoming system response.

The results of the present study suggest that time-based expectancy could also be employed in e-commerce scenarios, where the affective value of the displayed information is of central importance. It is generally acknowledge that timing (Cox & Dale, 2001; Tan, Benbasat, & Cenfetelli, 2016) as well as emotion (Hariharan, Adam, Teubner, & Weinhardt, 2016; Pappas, Kourouthanassis, Giannakos, & Chrissikopoulos, 2014) are critical for successful e-commerce applications. Yet, potential links between timing and emotion have not been explored. We suggest that time-based affect expectancy should be considered for designing a new generation of content sensitive scheduling algorithms for e-commerce applications. Increasing time-based affect predictability could foster cognitive processing of advertising information; reducing time-based affect predictability would suppress cognitive processing. Thus affect-sensitive scheduling algorithms could be applied to control consumers' cognition in emotion-laden commercial environments.

Open Questions and Future Research

Our study was based on the conceptualization of affect as composed of the two dimensions valence and activation, as suggested by the circumplex model of emotion (Russell, 1980). This might be seen as a limitation, because some current theories in the affective sciences investigate emotions without analyzing them as valence-activation compounds (Roseman, Spindel, & Jose, 1990). This applies also in the area of timing research: for example, duration estimation is affected by displayed disgust (Gil & Droit-Volet, 2011a), shame (Gil & Droit-Volet, 2011b), sadness, happiness, anger (Droit-Volet & Gil, 2009, 2016; Droit-Volet & Meck, 2007); for reviews, see Droit-Volet and Gil (2009) and Droit-Volet and Meck (2007).

We have chosen a two dimensional affect concept because this is most common in the literature on emotion-cognition interaction, but this choice was rather arbitrary. There is no apparent reason why time-based expectancy should not be possible for any other affective dimension, or discrete emotion. Thus, we assume that time-based affect expectancy would also be observed when intervals would be predictive for discrete emotions in appropriately rated affective stimulus sets (e.g., Briesemeister, Kuchinke, & Jacobs, 2011).

Another potential limitation was that we restricted our investigation to verbal stimuli. We have chosen words, because a word's valence is automatically processed, even if its valence is irrelevant to the task (Thomas et al., 2007; van Hooff et al., 2008). This does, however, also apply to emotional pictures, for example, of faces (Blau, Maurer, Tottenham, Nim, & McCandliss, 2007; Kolassa, Kolassa, Musial, & Miltner, 2007; Schacht & Sommer, 2009). In general, the emotional reactions to affective pictures and words are remarkably similar (Schacht & Sommer, 2009), the main difference being that a picture's valence is typically processed even faster than the valence of words (Frühholz, Jellinghaus, & Herrmann, 2011).Thus, we speculate that our findings would also generalize to the processing of affective pictures as long as their valence is predictable by time.

There is a further methodological aspect of our design potentially limiting the generalizability of our study. We employed the time-event correlation paradigm. This means that we induced expectancy implicitly by a certain frequency distribution of time-event combinations (see Introduction). However, in other fields of expectancy research, expectancy is often induced by explicit cues, informing participants at the beginning of each trial, about what to expect on that trial.

For example for event expectancy, only a minority of studies induces expectancy by event frequency (e.g., Hon, Ong, Tan, & Yang, 2012; Hyman, 1953; LaBerge & Tweedy, 1964), whereas the most common approach is to induce expectancy trialwise by explicit cues indicating which event is most likely (e.g., Buschman, 2015; Posner, 1980; Rosenbaum, 1980).

Likewise for time expectancy (see Introduction), a minority of studies manipulated frequencies of intervals to induce expectancy for a certain point in time (e.g., Baumeister & Joubert, 1969; Bevan, Hardesty, & Avant, 1965; Zahn & Rosenthal, 1966), whereas most studies employed the so called temporal orienting paradigm, where on each trial, a preceding cues informs about the duration of the current interval (e.g., Correa et al., 2010; Correa, Lupiáñez, Madrid, & Tudela, 2006; Coull, Cheng, & Meck, 2011; Coull & Nobre, 1998).

Though we have chosen to induce time-based expectancy by the time-event correlation paradigm, because this paradigm is well established in the time-based expectancy literature and it has been shown to reliably produce robust expectancy effects (e.g., Aufschnaiter, Kiesel, & Thomaschke, 2017; Kunchulia & Thomaschke, 2016; Thomaschke, Kunchulia, & Dreisbach, 2015; Thomaschke, Wagener, Kiesel, & Hoffmann, 2011; Volberg & Thomaschke, 2017). However, it would be interesting for future research to investigate time-based affect expectancy using a cue-based paradigm. In such a paradigm each combination of interval duration and valence would be overall equally frequent, but a cue preceding the interval would indicate whether a short interval is followed by a positive and a long interval by a negative word, or vice versa. We would predict that time-based affect expectancy would also be observable in such a scenario.

Conclusions

Our results show that humans implicitly form time-based expectancies for task-irrelevant valence and for activation, without becoming aware of the time-based predictability patterns. These findings can be explained by time-based semantic priming, or by preemptive compensation of either affective perception interference, or affective motor interference. In several domains of applied psychology (e.g., language processing, human-computer-interaction) time-based expectancy for affect has important implications for scheduling delays across computer users and telecommunication partners. However, future research needs to show whether time-based affect expectancy can also be formed for affective dimensions other than valence and activation, and whether our findings would generalize to affect conveyed by other modalities, such as, for example, pictures.

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