The specificity of temporal expectancy: Evidence from a variable foreperiod paradigm

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The specificity of temporal expectancy: Evidence from a variable foreperiod paradigm

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In speeded choice tasks with variable foreperiods (FPs), individuals behaviourally adapt to various frequency manipulations. Adaptations have been shown to frequencies of different stimulus–response events, to frequencies of different foreperiods, and to frequencies of different event–foreperiod combinations. We have investigated how participants adapt to a situation where all three frequency manipulations are done simultaneously. Three variable foreperiod experiments are reported. In Experiment 1, one target (the peak distributed target) appeared particularly frequently after one particular FP (the peak foreperiod), while another target was less frequent and equally distributed over all foreperiods. In Experiment 2, the equally distributed target was overall more frequent than the peak distributed one. In both experiments, performance advantages for the peak distributed target were specific to the peak foreperiod, and performance advantages at the peak foreperiod were specific to the peak distributed targets. A third experiment showed that, when two differently frequent target are both equally distributed over FPs, the performance distribution over FPs is not significantly different between both targets. Together, the results suggest that participants were able to simultaneously and specifically adapt to frequency manipulations in events, foreperiods, and event–foreperiod combinations.

Keywords: Temporal; Preparation; Conditional; Foreperiod; Expectancy.

Among the most important determinants of anticipatory behaviour is the ability to form expectations. Expectations can have temporal and nontemporal aspects. We usually have expectations about *what* will happen and about *when* it will happen. When, for example, I send a print job to my printer, I am expecting to hear the familiar auditory signal saying that the printer received it, but I am also expecting to hear that signal after an interval of about 10 s, the printer's typical response time.

Temporal and nontemporal aspects of expectancy have, however, previously been investigated largely in isolation. Some researchers have only manipulated expectancies for specific stimulus–response events, while keeping temporal aspects of the events constant or controlled (e.g., Hoffmann & Kunde, 1999; Posner, 1980). Others have exclusively focused on expectancies for certain points in time, irrespective of *what* happened at those points in time (Bausenhart, Rolke,

& Ulrich, 2008; Correa, Lupiáñez, & Tudela, 2006; Los, Knol, & Boers, 2001; Los & Schut, 2008; Steinborn & Langner, 2011). Only a few recent studies have dealt with expectancies for events and with expectancies for time together (Haering & Kiesel, in press; Kingstone, 1992; Rimmele, Jolsvai, & Sussman, 2011; Wagener & Hoffmann, 2010).

Two different approaches have been established to study event expectancies and time expectancies in an integrative manner. One approach manipulates the overall expectancy for events and the overall expectancy for certain points in time *independently* of each other within the same experiment. In a study by Kingstone (1992), for example, participants had to respond with key presses to certain types of symbols ("A" and "V"), which were preceded by a dual cue, separated by a variable interval (the foreperiod; FP from now on). One part of the cue predicted with 80% validity which symbol will appear, while the other part of the cue predicted the duration of the FP (i.e., when the symbol was likely to appear). Those predictions were, however, statistically independent of each other. The probability for a symbol did not affect the probability for the FP and vice versa. Participants were able to adapt to these dual predictions, in the sense of performing best when the event *and* the time were validly predicted.

The other approach manipulates, on the contrary, event and time expectancies in a completely conditional manner, while keeping overall expectancies constant. Wagener and Hoffmann (2010), for example, also employed speeded manual responses to symbols after a variable FP. But, in contrast to Kingstone (1992), the cue was merely a noninformative fixation cross. Instead of inducing expectancies by cues, Wagener and Hoffmann manipulated the *frequency* of event–time *combinations*. One of two stimulus–response events appeared more often in conjunction with one of two FPs, while the other event was more frequently paired with the other FP. Participants adapted to this redundancy in event–time pairings, by responding faster and more accurately to frequent event–FP pairs than to infrequent ones (see also

Thomaschke, Kiesel, & Hoffmann, in press; Wendt & Kiesel, in press).

Both approaches have, however, in common that they investigate the interaction of event and time expectancies in probabilistic scenarios that almost never appear in reality. Event-specific and temporal expectancies are usually neither absolutely independent from each other nor 100% conditional upon each other. Almost always, expectancies for events and expectancies for times (as manipulated in Kingstone, 1992) co-occur with expectancies for event–time combinations (as manipulated in Wagener & Hoffmann, 2010). When, for example, I am sending a print job to our network printer, probabilities for a certain event and a certain time are increased in an absolute and in a conditional way. On the one hand, the probability that the next sound ringing in our office is the printer signal (instead of, e.g., the phone) enormously increases, as well as the probability that the next sound in our office will ring after about 10 s (because this is the average response time of the printer). Note that this aspect was not modelled in Wagener and Hoffmann's (2010) design, where all events and times appeared—overall—with equal probability. On the other hand, my release of the print command also increases probabilities for an event–time combination (the printer's signal after the 10-s interval), because the probabilities for event and time are specific to each other. Neither the probability that, for example, the phone rings in about 10 s nor the probability that the printer signal will ring in 1 s (due to someone else having send a print job earlier) is increased. Note, that this aspect was not modelled in Kingstone's (1992) design, where the time-cue increased the probability of a FP for all events equally, and the event-cue increased the probability of one event at all times equally.

Currently, it has not been investigated empirically how one adapts to such a situation, where event and time probabilities co-occur in an unconditional and in a conditional manner. One possibility would be that the increase of absolute and conditional probabilities for time and event lead to a general expectancy for the frequent event and for the frequent time. This would mean that

elicitation of the print job increases my expectation for the printer's signal at *any* time (e.g., also immediately), and it also increases my expectation of any sound after 10 s (e.g., also the phone ring). Note, that under this hypothesis, one would still form the strongest expectancy for the combinations of the printer signal and the 10-s interval, but that the expectancies would not interact. Under this perspective, the formation of expectancies for specific combinations of time and event, as shown by Wagener and Hoffmann (2010), could be regarded a rare phenomenon, only present when all overall probabilities are balanced.

Another possible outcome would be that one forms expectancies in a *specific* manner. This would mean that elicitation of the print job increases my expectancy for the printer signal only at 10 s and increases my expectancy for the 10-s FP only for the printer signal. Note, that under this hypothesis, the expectancy for the printer signal is also increased in an overall manner, as well as the expectancy for the 10-s interval, but that these expectancies do interact with each other. Under this perspective, specific expectancies for combinations, as shown by Wagener and Hoffmann (2010), could be regarded as a ubiquitous phenomenon, which is present wherever increases of the probability of an event is conditional upon a certain FP, or vice versa.

The experiments presented here enable one to dissociate between both hypotheses, by manipulating frequencies of FPs, of events, and of event–FP combinations together, and measuring whether expectations for events and expectations for FPs interact with each other.

EXPERIMENT 1

In a two-alternative forced-choice task with 15 different FPs, we presented one FP highly frequently, while the others were equally rare. The overall frequency of this one peak-FP was, however, due to only one stimulus–response event appearing often at this FP, while another stimulus–response event was equally distributed over all FPs. Expectancy was measured as preparedness

for an event or at a FP (i.e., response speed and accuracy). Generalized expectancy would manifest itself in main effects of event and FP on preparedness, but no interaction. Specific expectancy would lead to main effects and an interaction.

Method

Participants
A total of 12 students (5 female, 7 male) participated in exchange for course credits (mean age = 24.16 years, $SD = 3.69$). They were right-handed and had normal or corrected-to-normal vision.

Apparatus and stimuli
Stimulus presentation and collection of responses were performed by an IBM-compatible computer with a 17-inch VGA-display controlled by E-Prime (Schneider, Eschman, & Zuccolotto, 2002). Responses were done with the index and middle fingers of the right hand on two adjacent buttons on a Serial Response Box (Psychology Software Tools), which was centrally aligned in front of the computer screen. Stimuli were a white filled circle and a white filled square (approximately 2 cm × 2 cm) on dark grey background. The fixation cross was the "+" symbol (typeface "Arial", 1.3 cm × 1.3 cm). All stimuli were centrally presented.

Procedure
Each trial began with a presentation of a fixation cross. The fixation cross stayed on the screen for the duration of the FP, which varied from trial to trial. When the FP had elapsed, the fixation cross was substituted by the target stimulus. FPs ranged from 100 ms to 1,500 ms in steps of 100 ms and were differently distributed over target stimuli. One target stimulus appeared, in each block, 2 times after each possible FP (the uniformly distributed target), while the other target appeared 92 times after 500 ms and only 2 times after each one of the remaining FPs (the peak distributed target).

The assignment of targets to the peak and to the equal FP distribution was counterbalanced across participants. The assignment of stimuli to

responses was also counterbalanced. When participants did not answer within 1,000 ms after target onset, the German words "bitte schneller" (faster, please) were displayed in red for 1,000 ms. When participants pressed the wrong response key, the German words "falsche Taste" (wrong key) were displayed in red for 1,000 ms. The intertrial interval was 500 ms. Before the experiment, participants were instructed to respond as fast and accurately as possible. In each trial, the FP and the target were chosen randomly without replacement from the FP–target distributions. The experiment lasted for eight blocks of 150 trials each.

Results

Responses that were too late (>1,000 ms, 2.84% of all trials) have been removed from the analysis. Analysis of errors was restricted to timely, but erroneous, presses of the wrong response key. These trials have been removed from the RT analysis. Mean percentage of errors and mean RTs were computed for each participant for each combination of FP (ranging from 100 ms to 1,500 ms) and stimulus–response event (peak distributed target vs. uniformly distributed target). Average data across all participants are presented in Figure 1.

In order to determine whether the overall distribution of FPs affected responses to the two stimuli differently, we conducted a repeated measures 2 × 15 analysis of variance (ANOVA) on reaction times (RTs) with the independent variables event and FP. We found a main effect of event, $F(1, 11) = 25.532$, $p < .001$, $\eta_p^2 = .70$, reflecting faster responses for the more frequent target, and a main effect of FP, $F(4, 154) = 21.564$, $p < .001$, $\eta_p^2 = .66$. Most importantly, we also found an interaction between event and FP, $F(4, 154) = 7.525$, $p < .001$, $\eta_p^2 = .40$, indicating that the overall distribution of FPs affected the performance for both targets differently.

A similar pattern was observed in a further ANOVA for error rates. The main effect for event was significant, $F(1, 11) = 28.54$, $p < .001$, $\eta_p^2 = .72$, as well as the interaction between event and FP, $F(14, 154) = 2.32$, $p = .006$, $\eta_p^2 = .17$.

Thus, response accuracy was also affected differently by the FP distribution, depending on whether the peak distributed or the uniformly distributed target appeared.

Discussion

Analyses of the error rates and of RTs revealed an Event × FP interaction. The high frequency of the one FP of 500 ms affected performance for the frequent stimulus–response event differently from that for the infrequent stimulus–response event. Thus, participants' expectancy for the frequent stimulus–response event was temporally specific, or, put another way, expectancy for the frequent FP was specific to the frequent stimulus–response event.

EXPERIMENT 2

The previous experiment indicates that high frequency of an FP induces temporal expectancy primarily for that stimulus–response event that the high frequency is due to. Experiment 2 tests whether the expectancies induced by an overall *infrequent* FP can also be specific to a stimulus–response event, when this stimulus–response event is relatively frequent at that FP, compared to other FPs. Again, we compare a frequent stimulus–response event with an infrequent stimulus–response event. But now, the overall frequent stimulus–response event was equally distributed over FPs, while the overall infrequent stimulus–response event was peak distributed at 500 ms and appeared only very rarely at all other FPs. If specific temporal expectancy can only be formed for overall highly frequent stimulus–response events, we would expect no interaction between temporal-expectancy and event-expectancy.

When, on the contrary, specific temporal expectancy is independent of the overall frequency of the expected stimulus–response event, we would expect an interaction between temporal expectancy and event-expectancy.
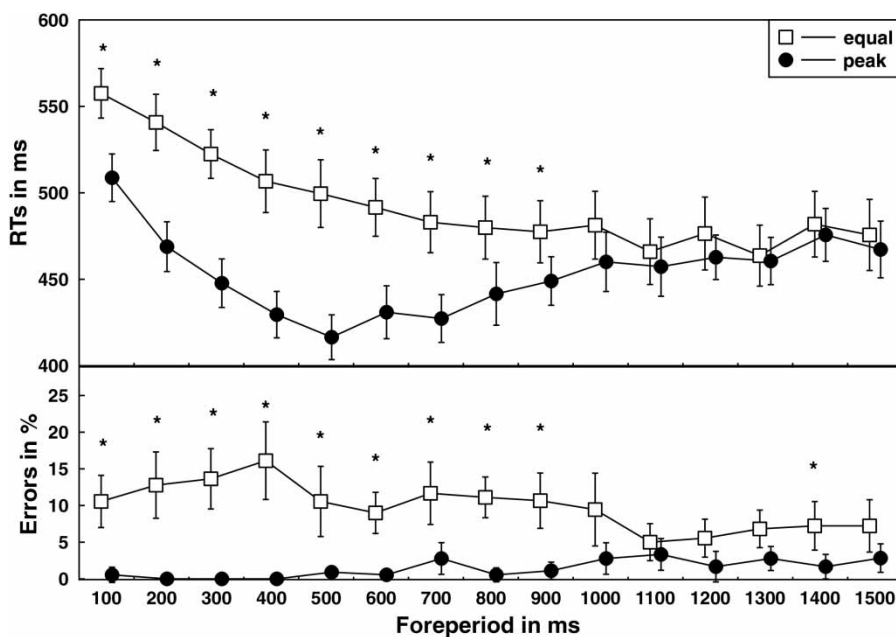
Figure 1. *Experiment 1: Mean reaction times (RTs; upper portion), and mean percentages of errors (lower portion) are shown in dependence of foreperiods and targets. Error bars represent 1 standard error, and asterisks denote significant differences at the $\alpha = .05$ level.*

Method

Participants

A total of 12 students (8 female, 4 male) participated in exchange for course credits (mean age = 25.58 years, $SD = 6.302$). They had normal or corrected-to-normal vision.

Apparatus and stimuli

The apparatus and stimuli were identical to the ones used in Experiment 1 except that responses were executed on two external response keys with the left and right index fingers.

Procedure

FPs ranged from 100 ms to 1,500 ms in steps of 100 ms and were differently distributed over target stimuli. One target stimulus appeared, in each block, 8 times after each possible FP (the uniformly distributed target), while the other target appeared 46 times after 500 ms and only 1 time after each one of the remaining FPs (the peak distributed target). Thus, the equally distributed target

appeared, overall, twice as often as the peak distributed target. The experiment lasted for eight blocks of 150 trials each.

Results

Average data across all participants are presented in Figure 2.

In order to determine whether the overall distribution of FPs affected responses to the two stimuli differently, we conducted a repeated measures 2 × 15 ANOVA on RTs with the independent variables event and FP. We report Greenhouse–Geisser corrected values, where Mauchly's test for sphericity was significant. We found a main effect of event, $F(1, 11) = 21.266$, $p = .001$, $\eta_p^2 = .66$, reflecting faster responses for the more frequent target, and a main effect of FP, $F(5, 55) = 8.545$, $p < .001$, $\eta_p^2 = .44$. Most importantly, we also found an interaction between event and FP, $F(4, 41) = 3.210$, $p = .024$, $\eta_p^2 = .226$, indicating that the overall distribution of FPs affected the performance for both targets differently.
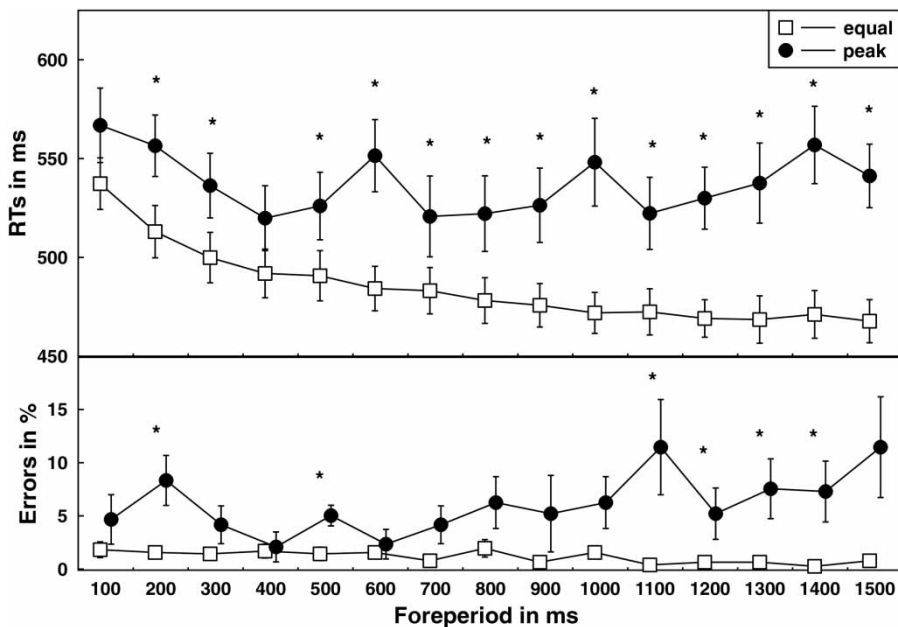
Figure 2. Experiment 2: Mean reaction times (RTs; upper portion), and mean percentages of errors (lower portion) are shown in dependence of foreperiods and targets. Error bars represent 1 standard error, and asterisks denote significant differences at the α = .05 level.

A further ANOVA has been conducted for error rates. The main effect for event was significant, $F(1, 11) = 22.57$, $p = .001$, $\eta_p^2 = .672$. The main effect of FP ($p = .440$) and the interaction ($p = .111$) were not significant.

Discussion

As in Experiment 1, we found in the RTs a significant interaction effect between expectancy for FP and expectancy for a stimulus–response event. The unequal distribution of the infrequent event over FPs affected performance for the frequent stimulus–response event differently from that for the infrequent stimulus–response event. Thus, participants' expectancy for the infrequent stimulus–response event was temporally specific, or, put another way, expectancy for the frequent FP was specific to the infrequent stimulus–response event. These results suggest that high overall frequency of a stimulus–response event is no precondition for the formation of temporally specific expectancy for that event. Instead, specific

temporal expectancy seems to be present for overall rare events, as well.

The data do also show that specific temporal expectancy is not exactly temporally precise in the context of many similar FPs. In a previous study, we have shown that specific temporal expectancy does not always lead to an event-specific RT minimum at the event's most frequent FP, but that this minimum can sometimes be found at FPs next to the peak FP (Thomaschke, Wagener, Kiesel, & Hoffmann, 2011). This pattern is familiar from studies on general temporal expectancy with peak FP distributions (Baumeister & Joubert, 1969; Karlin, 1966) and is probably due to an imprecision of human time estimation (Grondin, 2010). In the present study, RTs were shortest at the 400-ms FP, not at the peak FP of 500 ms. Furthermore, at all FPs, RTs were shorter for the overall frequent event than for the infrequent one, although the overall infrequent event was at its peak FP more likely than the overall frequent event. Thus, specific temporal expectancy consists in a tendency to expect an

event rather at a relatively broad temporal region instead of a particular FP (see Thomaschke et al., 2011, for an investigation of the temporal precision of specific temporal expectancy).

EXPERIMENT 3

In the previous experiments, participants' performance differed over FPs for events that were differently distributed over FPs (i.e., peak distributed vs. equally distributed). We concluded that the different performance over FPs was caused by the different distribution of events over FPs. However, in both experiments, the events also differed in overall frequency. An alternative interpretation would be that the mere difference in overall event frequency causes the difference in distribution of performance over FPs for the events. According to this explanation, performance for overall frequent events is, in general, differently distributed over FPs from performance for overall infrequent events, independently of how the events themselves are distributed over FPs. In order to test this hypothesis, we compared performance for an equally distributed frequent stimulus–response event with the performance for an equally distributed infrequent stimulus–response event. An interaction between expectancy for FP and expectancy for event, despite the identical distribution of both events over FPs, would suggest that different frequency of events alone can induce different temporal expectancies for those events. The absence of an interaction would suggest that the different distributions of events over FPs in Experiments 1 and 2 had induced the specific temporal expectancy in those experiments. Our previous conclusion concerning Experiments 1 and 2 would be supported.

Method

Participants
A total of 12 students (8 female, 4 male) participated in exchange for course credits (mean age = 25.08 years, $SD = 3.75$). They had normal or corrected-to-normal vision.

Apparatus and stimuli
Apparatus and stimuli were identical to those in Experiment 2.

Procedure
FPs ranged from 100 ms to 1,500 ms in steps of 100 ms and were differently distributed over target stimuli. One target stimulus appeared, in each block, 2 times after each possible FP (the infrequent target), while the other target appeared 8 times after each possible FP (the frequent target). Thus, both targets were equally distributed over FPs. The experiment lasted for eight blocks.

Results

Average data across all participants are presented in Figure 3. The data of 2 participants indicated that they were not sufficiently committed to the task. One of them pressed the wrong key on more than 25% of the trials with one of the targets, and another participant responded overall more than 2 standard deviations (49) slower than the average (467 ms). Both have been excluded from further analyses.

In order to determine whether performance is distributed differently over FPs for frequent and infrequent events, we conducted a repeated measures 2×15 ANOVA on RTs with the independent variables event and FP. We found a main effect of event, $F(1, 9) = 27.47$, $p = .001$, $\eta_p^2 = .75$, reflecting faster responses for the more frequent target, and a main effect of FP, $F(5, 40) = 17.296$, $p < .001$, $\eta_p^2 = .66$. Most importantly, we did not find an interaction between event and FP, $F(6, 50) = 1.961$, $p = .094$, $\eta_p^2 = .179$, indicating that performance was not differently distributed over FPs for frequent and infrequent events.

A similar pattern was observed in a further ANOVA for error rates. The main effect for event was significant, $F(1, 9) = 10.686$, $p = .010$, $\eta_p^2 = .543$, but the interaction between event and FP was not significant, $F(5, 40) = 1.478$, $p = .223$, $\eta_p^2 = .141$.
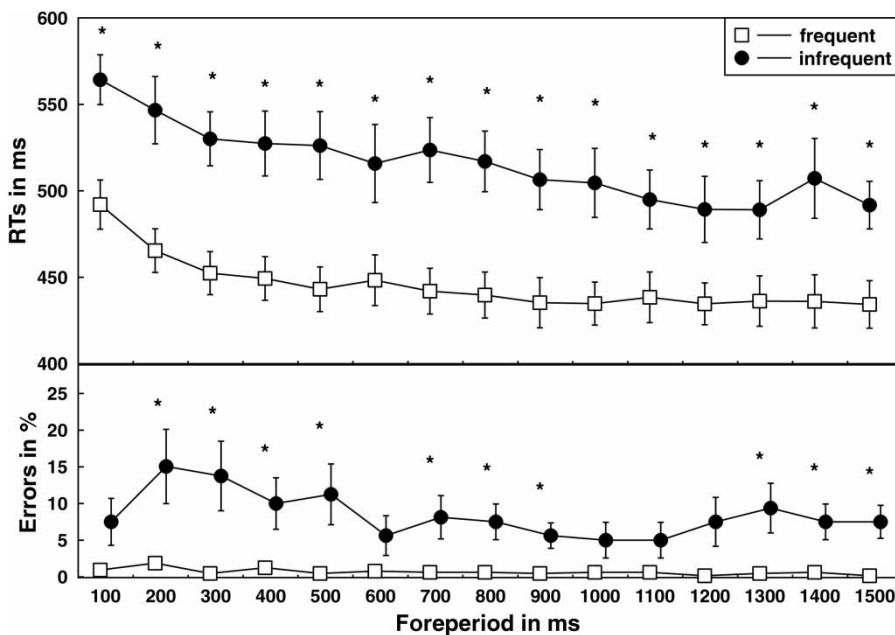
Figure 3. *Experiment 3: Mean reaction times (RTs; upper portion), and mean percentages of errors (lower portion) are shown in dependence of foreperiods and targets. Error bars represent 1 standard error, and asterisks denote significant differences at the $\alpha = .05$ level.*

Discussion

We compared the performance for a frequent and for an infrequent stimulus–response event. Both events were equally distributed over FPs. We found effects for temporal expectancy and for event expectancy, of quite comparable size to those in Experiments 1 and 2. But, in contrast to those experiments, we did not find an interaction between both expectancies.

The results clearly show that the formation of event-specific temporal expectancy requires a differential distribution of events over FPs, and that a mere difference of event frequency is not sufficient.

GENERAL DISCUSSION

We investigated how participants adapt to a situation where probabilities for stimulus–response events and for FPs differ in an overall manner, as well as in a conditional way. We conducted

two experiments, where differently frequent events were differentially distributed over FPs. In Experiment 1, the frequent event was peak distributed, whereas the infrequent event was equally distributed over FPs. In Experiment 2, the frequent event was equally distributed, whereas the infrequent event was peak distributed over FPs. We asked whether temporal expectancy for the peak distributed event would also generalize to the equally distributed event, or whether, on the contrary, expectancies would be specific to the combination of the peak distributed event and its characteristic FP. Generalized expectancy would have predicted two main effects but no interaction between the factors event and FP, while specific expectancy predicted main effects and an interaction between event and FP.

We found an interaction in both experiments, suggesting event-specific temporal expectancy. In a third control experiment, we compared two differently frequent, equally distributed events, to exclude the possibility that a mere difference in

frequency can induce different temporal expectancies for two events. We found, as expected, no interaction between event expectancy and FP expectancy.

General and specific temporal expectancy

Taken together, the results suggest that whenever probabilities for event and time are conditional upon each other, expectancy is always specific to event–time combinations, no matter whether overall expectancies differ (as in the present study) or not (as in the study by Wagener & Hoffmann, 2010). When one event is frequent overall, it does not increase the expectancy for this event as such, but only specific for the FP that it is frequent at. Put another way, when one FP is frequent, it does not increase the expectancy for this FP as such, but only specific to the event that appeared frequently at this FP. Thus, behavioural adaptation to event–time combinations is not restricted to the rare cases where overall frequencies are balanced, and other sources for event or time expectancy are absent, but instead behavioural adaptation to event–time combinations seems to be a ubiquitous phenomenon, present wherever one combination of event and time is more frequent than another one.

Indeed, performance for the event was not only enhanced at precisely the FP at which the event was frequent in Experiments 1 and 2. We conjecture that the increased expectancy of the frequent event is not precisely restricted to the frequent FP, but rather extends to some degree to other short FPs as well (see Figures 1 and 2). This is consistent with an earlier study on specific temporal expectancy (Thomaschke et al., 2011) and is probably due to inaccuracies in estimating time intervals of this range.

Motor and perceptual aspects of specific temporal expectancy

Adaptation to the overall frequency distribution of FPs has been intensely researched in situations where the events have been balanced over FPs. Yet, our results suggest that whenever one expects a certain FP, this expectancy is to a large degree

event-specific. This poses the question of exactly which components of temporal expectancy are specific for events, and which components might be general (i.e., event-independent temporal expectancies). The formation of expectancy for an upcoming event after a certain FP is a highly complex process. Temporal expectancies have been demonstrated for perceptual aspects of a stimulus–response event (e.g., Correa, Lupiáñez, & Tudela, 2005; Lange, 2010; Lange, Rösler, & Röder, 2003; Rolke & Hofmann, 2007; Seibold, Bausenhart, Rolke, & Ulrich, 2011; Seibold, Fiedler, & Rolke, 2011), as well as for motor aspects (e.g., Boulinguez, Ballanger, Granjon, & Benraiss, 2009; Boulinguez, Jaffard, Granjon, & Benraiss, 2008; Duclos, Burnet, Schmied, & Rossi-Durand, 2008; Duclos, Schmied, Burle, Burnet, & Rossi-Durand, 2008; Spijkers, 1990). Furthermore, several other processing stages between stimulus perception and response execution are affected by temporal expectancy (see Bausenhart, Rolke, Seibold, & Ulrich, 2010; Hackley et al., 2009; Hackley, Schankin, Wohlschlaeger, & Wascher, 2007; Rolke, 2008, for reviews). Some of these components of temporal expectancy might be specific to events, while others might be general. One might, for example, conjecture that, on the one hand, the auditory expectancy to hear the printer sound 10 s after sending a print job is specific to the printer signal, but that, on the other hand, the motor expectation for the required response might be general, in the sense that it applies to any response and not only to grasping the paper from the printer. As stimuli and responses were, in the present experiment, always scheduled together to a certain FP, this question cannot be answered here and would require further research.

Specific temporal expectancy in animal timing

Our study was restricted to forced-choice experiments in humans, but similar research questions do also apply to analogous free-choice paradigms in animal timing research. In those studies, animals are placed in an operant chamber with

two or more levers. Reward for each lever is only given when the lever is pressed after a lever-specific time interval (Arantes & Machado, 2011; Church & Deluty, 1977; Killeen & Fetterman, 1993; McClure, Saulsgiver, & Wynne, 2011; Meck, 1983; Roberts & Church, 1978). Other studies reward animals when moving to a certain location only after a certain location-specific interval (Cowles & Finan, 1941; Heron, 1949; Machado & Keen, 2003). Animals can quickly adapt to these conditions, in the sense of pressing the levers more often after their characteristic intervals than after other intervals—a clear case of specific temporal expectancy. In those studies, reward is typically given overall equally often after each interval and for each lever (or location), but some combinations of lever and interval are rewarded, while others are not. A similar question arises, as with the previously discussed forced-choice paradigms in humans (Wagener & Hoffmann, 2010): Is this specific temporal expectancy effect restricted to situations in which no general time or event expectancy is possible, due to balanced frequencies (i.e., where different levers and different intervals are rewarded overall equally often)? Or can specific temporal expectancy co-occur with general event expectancy and general temporal expectancy?

In terms of the free-choice paradigms, the questions would be: When one lever is much more often rewarded than the other one, and when this advantage is due to only one time interval, would the resulting preference for the lever be specific to that time interval, or would it also emerge at other time intervals? When specific temporal expectancy can co-occur with unspecific expectancy, one would expect the following behaviour: The frequently rewarded lever will be pressed overall more often (due to general event expectancy), but this advantage will be restricted to the interval at which the lever was frequently rewarded (due to specific temporal expectancy). After the other interval, both levers would be pressed equally often. Likewise, presses will occur overall more often after the frequently rewarded interval (due to general temporal expectancy) than after the infrequently rewarded one. But this advantage will be restricted to the lever that was more

frequently rewarded after the frequent interval (due to specific temporal expectancy). The other lever will be pressed equal often after each interval.

When specific temporal expectancy can, on the other hand, not occur in the context of general temporal expectancy, one would expect that the frequently rewarded lever will be pressed more frequently, but that this tendency would be observable at both intervals. Likewise, one would expect that more presses would occur after the frequently rewarded interval, but that this tendency would be observable for both levers.

In their focus on combinations of time and event, the cited animal timing studies are comparable with Wagener and Hoffmann's (2010) study on specific temporal expectancy in humans. Yet, the free-choice aspect in these studies relates them rather to explicit time judgement studies in humans (Allan & Gibbon, 1991; Grondin, 2010). However, as Piras and Coull (2011) have recently shown that explicit time judgement and implicit temporal expectancy draw partly on the same timing mechanisms, we suggest that our results are transferable to animal timing.

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