Age-Related Differences in Time-Based Event Expectancies

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Abstract
The ability to form time-based event expectancies is one of the most important determinants of anticipative behavior. The aim of the present study was to determine whether healthy aging influences the formation of time-based event expectancies. Ten older adults with ages ranging between 60 and 73 years and ten younger adults with ages ranging between 20 and 32 years participated. We employed a binary choice response task mimicking a computer game, in which two target stimuli and two pre-target intervals appeared overall equally often. One of the targets was paired with the short interval and the other target with the long interval in 80% of the trials. Our results showed that younger adults responded more rapidly to frequent interval–target combinations than to infrequent combinations, suggesting that the young participants formed time-based event expectancies. In contrast, the ability to form time-based event expectancies was reduced for older participants. The formation of time-based event expectancies seems to change during healthy aging. We propose that this age-related difference is due to age-related expectation deficits or a reduction of attentional capacities, rather than to deficits in timing abilities.

Keywords
Aging, temporal cognition, associative learning, time-based expectations, attentional control

1. Introduction

Many cognitive capabilities decline during healthy aging, including basic information processing components such as processing speed (Eckert et al., 2010), episodic memory (Kinugawa et al., 2013), and working memory (Cowan et al., 2006). Expectancy seems to play an important role in age-related cognitive decline. For

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instance, Bollinger et al. (2011) found that older adults, in contrast to younger people, did not show any benefits in working memory and long-term memory performance for face stimuli when a stimulus category was expected, suggesting expectation-based memory deficits in aging. This behavioral deficit was associated with lowered expectation-mediated neural biasing by the frontoparietal attention network. On the basis of their findings, they proposed the *expectation deficit hypothesis* of cognitive decline during aging (Bollinger et al., 2011).

There are also many age-related changes affecting attention-related functions (Kok, 2000; Zanto et al., 2011). For example, Zanto et al. (2011) reported evidence for age-related decline in temporal attention. Using a temporally cued target–response task while recording EEGs, they found that older adults hardly used temporal cues to orient attention in time and, further, showed neural deficit in temporal attention, suggesting an expectation deficit in healthy aging.

Moreover, extensive research (Baudouin et al., 2006; Espinosa-Fernández et al., 2003; Gooch et al., 2009; Lustig & Meck, 2011; Rueda & Schmitter-Edgecombe, 2009; Wild-Wall et al., 2008) has demonstrated the effects of aging on timing performance. For example, aged adults are less accurate in performing a duration comparison task than younger adults (Dormal et al., 2012); during the production of syncopated movements, older adults required slower tapping rates than young adult participants (Stegemöller et al., 2009). The general finding from these studies is that timing performance declines with healthy aging. However, human timing fulfills two fundamentally different functions in structuring our cognition. On the one hand, timing mechanisms orient our cognitive capacities to certain points in time: We expect *when* we have to process the next stimulus-response event (Los & Van den Heuvel, 2001a; Steinborn et al., 2009). When delay durations in our environment are predictable, we schedule our cognitive system to behaving optimally at that point in time, where it is most likely that the next stimulus-response episode will have to be processed. This is typically referred to as *time expectancy*. On the other hand, our cognitive system uses time as a cue to orient our cognitive capacity to certain types of stimulus-response events. This means that, based on time, we also expect *which* stimulus-response episode needs to be processed next. When the duration of a delay predicts which event will be most likely at the current moment, our cognitive system adapts to this predictability and is dynamically biased to that event that is most likely at the current point in time. This is commonly referred to as *time-based expectancy*.

Time-based event expectancy allows us to anticipate an event, based on the duration of an interval (Kunchulia & Thomaschke, 2016; Thomaschke & Haering, 2014). For example, when we send out a print job to our printer, we are expecting to hear the familiar auditory signal saying that the printer received it after an interval of about 10 s, the printer's typical response time (Thomaschke et al., 2011). When the 10 s pass by without any signal, our expectancy changes towards an error signal. Thus, we are able to exploit the temporal structure of past events to predict when a future event will occur (Schwartze & Kotz, 2015). Repeated

experience of the same temporal structures leads to adaptation to these structures, so that we orient attention to specific points in time and can thus respond more quickly when events occur at the expected time (Thomaschke & Dreisbach, 2013). Continuously tracking the temporal regularity within sensorimotor domains is essential for the acquisition of time-based event expectancy. Although the exact neural mechanisms underlying time-based event expectancy are still largely unknown, some brain structures playing a key role in motor behavior have been linked to temporal processing (Coull et al., 2011). Age-related changes in these brain structures are well established (Seidler et al., 2010). We speculate that these changes might have an effect on the formation of time-based expectancy during aging.

The time–event correlation paradigm has been extensively used to study time-based event expectancy (Wagener & Hoffmann, 2010; see Kunchulia & Thomaschke, 2016 and Thomaschke, Kunchulia, & Dreisbach, 2015 for detailed overviews). In this paradigm two target stimuli and two preparatory intervals—foreperiods—appear equally often overall, but one of the targets is paired with the short preparatory interval and the other target with the long preparatory interval, in 80% of the trials. The formation of time-based event expectation leads to faster responses to frequent foreperiod-target combinations, relative to infrequent ones (Thomaschke et al., 2011).

Recently, we found that time-based event expectancy in young adults was more pronounced with longer intervals (Thomaschke et al., 2015). Using the same paradigm as Thomaschke et al. (2015), we found that the ability to form time-based event expectancies was developed in school-age children but, in contrast to adults, temporal predictions were more optimal with shorter foreperiods (Kunchulia et al., 2016). In the present study, we ask the question whether the ability to form time-based event expectancies changes during healthy aging. We used a binary choice response task, realized as a basic computer game (Thomaschke et al., 2015). A gamification strategy was applied, because by stimulating cognition and enjoyment (Tong & Chignell, 2013), it might reduce any differences in motivation that are common in assessing performance differences in aging by standard laboratory experiments (Hess et al., 2009).

Since older adults show general expectation deficits, and the general timing abilities decline with aging, we hypothesized that older adults may also show a decline in the time-based event expectancies.

2. Materials and Methods

2.1. Participants

Twelve older adults (mean age = 65.5 years, SD = 3.97, 5 male) and ten younger adults (mean age = 24.3 years, SD = 4.7, 3 male) participated. The study was approved by the local Bioethics Committee of Ivane Beritashvili Center of

Experimental Biomedicine, and was performed in accordance with the Declaration of Helsinki. Informed consent was obtained from all participants. Older participants were free of significant health problems. All older participants took part in the Montreal Cognitive Assessment (MoCa; Nasreddine et al., 2005). Two older participants had scores below 26 on the MoCA, indicating mild cognitive impairment and consequently were excluded from the analysis.

2.2. Apparatus

We used E-Prime2 (Schneider et al., 2002) for running the experiment and for collecting data. Data were collected on a Windows PC with LCD display (screen resolution 1280 × 800 pixels). Responses were collected using a standard optical mouse.

2.3. Procedure

The participants performed a binary choice response task, mimicking a basic computer game. The task was to chase a carrot with a donkey character, which moved repeatedly from the bottom to the top of the screen in a zigzag left-to-right course, until it could finally be caught at a fence in the upper border of the screen (see Fig. 1). One experimental block consisted of 25 carrot chases, each chase being composed of six jumping steps. When the carrot jumped to the upper left of
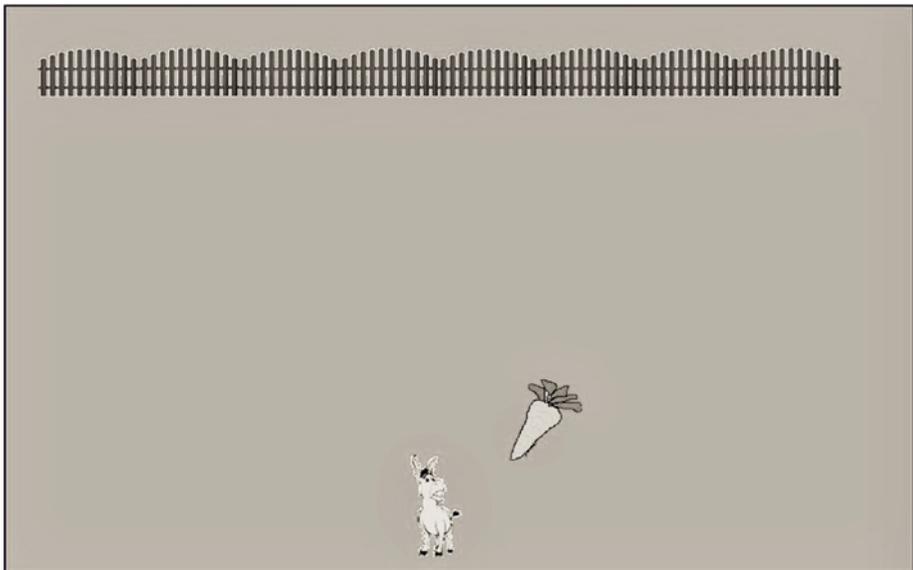

Figure 1. Schematic illustration of the layout of the choice response task. The donkey starts chasing the carrot at the bottom of the screen and 'captures' it on the fence.

the donkey, participants had to press the left mouse button in order to make the donkey follow the carrot leftward (pressing the right mouse button moved the donkey to the right). After the mouse click, the donkey immediately jumped on the carrot. After a short or long response-stimulus interval (i.e., from mouse click to carrot movement), the carrot jumped away again. This response–stimulus interval represented the foreperiod in this task. The carrot's movement was either diagonally upwards left, or diagonally upwards right.

When the participants pressed the wrong key or pressed the key before the carrot had jumped, an error message was displayed, an aversive tone was played over the headphones, and the game was paused for 3 s (see Kunchulia & Thomaschke, 2016; Szameitat et al., 2009; Thomaschke et al., 2015). The experimental session lasted for four blocks.

We tested performance for two experimental conditions: (1) with short (300 ms) and (2) long (600 ms) temporal distance between the two foreperiods. We used a 300/600 ms (short/long) pair for the short temporal distance condition and a 600/1200 ms (short/long) foreperiod pair for the long temporal distance condition. For half of the participants the short foreperiod predicted a left, and the long foreperiod predicted a right movement of the carrot with 80% validity. For the other half, this relation was inverted. Participation took place across two days and the task conditions were counterbalanced across the two experimental sessions.

Expectancy was measured as preparedness for an event (i.e., carrot's movement direction) at a foreperiod. This means if participants formed time-based expectancies they would respond faster and more accurately to frequent combinations of foreperiod and direction (i.e., when foreperiod duration predicted the carrot's next movement direction with $p = 0.8$) than to infrequent combinations (i.e., when the carrot's next movement direction was not predictable by foreperiod duration [$p = 0.2$]).

2.4. Data Analyses

Response time (RT) and error rate from the fourth block (150 trials) were each analyzed with a mixed analysis of variance (ANOVA) with the between-subjects factor of group (old vs. young), and the within-subjects factors of temporal distance (short vs. long) foreperiod duration (short vs. long) and frequency (frequent vs. infrequent foreperiod–event combination).

Error trials (1,06% for young, 0,77% for old) and trials with RTs deviating from the condition mean by more than three standard deviations (0,33% for young, 0,38% for old) were excluded from the RT analysis (Bush et al., 1993). In addition, the trials following errors and the initial trial of the block were excluded from the RT analysis and the error analysis. This screening procedure is exactly the same as in our previous studies using this paradigm (see, e.g., Thomaschke et al., 2015).

3. Results

From the fourth block we calculated mean RTs and mean percentages of errors separately for each participant, for each foreperiod, and for each condition. Table 1 shows the average values for younger and older adults.

A mixed ANOVA on the RTs revealed a significant main effect for Group, $F(1, 18) = 17.81$, $p = 0.001$, due to slower RTs by older adults ($M = 547.589$, SD $= 82.1$), than by younger ones ($M = 392.62$, SD $= 82.1$). There was also a significant main effect for the within-subjects factors of frequency, $F(1, 18) = 6.4$, $p = 0.021$, and of foreperiod duration, $F(1, 18) = 7.3$, $p = 0.014$. However, there was no significant main effect for the factor temporal distance, $F(1, 18) = 2.6$, $p = 0.124$. We found that frequency interacted with foreperiod, $F(1, 18) = 9.2$, $p = 0.007$. However there was no significant interaction between age groups and frequency, $F(1, 18) = 0.9$, $p = 0.35$. We also did not observe a significant interaction between age groups and any other factor such as foreperiod duration, $F(1, 18) = 0.3$, $p = 0.56$, or temporal distance, $F(1, 18) = 0.4$, $p = 0.46$ (for more details, see Table 2).

Table 1.

Means (M) and standard deviations (SD) for response times (RTs) and error rate for all foreperiods (FPs), conditions and groups.

	Young		Old	
	RT	Error rate	RT	Error rate
Short condition, short FP, frequent	396.8 (41.97)	0.879 (1.22)	557.9 (153.59)	0.812 (1.72)
Short condition, short FP, infrequent	373.57 (29.47)	2.91 (6.22)	553.86 (98.25)	0.00 (0.00)
Short condition, long FP, frequent	336.68 (41.06)	0.8 (1.17)	516.89 (84.97)	0.51 (0.83)
Short condition, long FP, infrequent	391.33 (53.68)	2.2 (5.08)	532.83 (115.44)	1.22 (2.58)
Long condition, short FP, frequent	419.77 (82,71)	1.08 (1.54)	555.78 (135.45)	0.154 (0.48)
Long condition, short FP, infrequent	425.58 (107.95)	0.00 (0.00)	552.5 (138.44)	1.48 (3.13)
Long condition, long FP, frequent	382.5 (60.47)	0.98 (1.51)	544.12 (125.41)	0.89 (1.27)
Long condition, long FP, infrequent	414.67 (60.07)	1.57 (3.37)	566.67 (89.34)	0.00 (0.00)

Table 2.
A mixed analysis of variance (ANOVA) with the between-subjects factor of group (old vs. young), and the within-subjects factors of temporal distance (TD, short vs. long), foreperiod duration (short vs. long), and frequency (frequent vs. infrequent foreperiod–event combination) for RT and error rate.

	dfs	RT			Error rate		
		F	*p*	η^2	*F*	*p*	η^2
TD	1, 18	2.6	0.124	0.127	1.6	0.219	0.083
FP	1, 18	7.3	0.014	0.291	0.0	0.818	0.003
Frequency	1, 18	6.4	0.021	0.263	1.4	0.251	0.072
Group*TD	1, 18	0.4	0.49	0.026	1.5	0.224	0.081
Group*FP	1, 18	0.3	0.57	0.017	0.0	0.89	0.001
Group*frequency	1, 18	0.9	0.35	0.049	0.8	0.35	0.047
TD*FP	1, 18	1.7	0.19	0.091	0.0	0.85	0.002
TD*FP*group	1, 18	2.5	0.12	0.125	1.6	0.21	0.08
TD*frequency	1, 18	0.1	0.72	0.007	0.9	0.34	0.05
TD*group*frequency	1, 18	0.0	0.98	<0.001	1.6	0.214	0.085
FP*frequency	1, 18	9.2	0.007	0.339	0.0	0.93	<0.001
FP*frequency*group	1, 18	1.3	0.25	0.072	0.1	0.66	0.01
TD*FP*frequency	1, 18	0.3	0.56	0.019	0.2	0.674	0.012
TD*FP*frequency*group	1, 18	0.5	0.46	0.03	3.9	0.063	0.179

Despite the lack of any significant interaction between age group and other factors, the numerical result patterns for both groups appeared strikingly different at visual inspection. Although a difference is not statistically warranted—probably due to a lack of statistical power—we ran separate explorative analyses on both groups, in order to describe these different patterns in more detail.

Separate analyses of variance (ANOVA) for groups showed a significant main effect for frequency for young adults, $F(1, 9) = 23.7$, $p = 0.001$ (see Table 3, Fig. 2) that were mainly due to the fact that the young participants responded faster to frequent combinations than to infrequent combinations, but old adults did not, $F(1, 9) = 0.7$, $p = 0.421$ (see Table 3, Fig. 2). This means that time-based expectancy was formed for young adults. The separate analyses of variance (ANOVA) for groups also showed that the interaction between frequency and foreperiod was significant for the younger adults, $F(1, 9) = 10.0$, $p = 0.011$, due to a stronger frequency effect for the long than for the short foreperiods, but not for older adults, $F(1, 9) = 1.5$, $p = 0.245$. The young adults responded also more rapidly to long than to short foreperiods, $F(1, 9) = 7.5$, $p = 0.023$, but older adults did not,

Table 3.

Separate analysis of variance (ANOVA within-subjects factors of temporal distance (TD, short vs. long), foreperiod duration (short vs. long), and frequency (frequent vs. infrequent foreperiod–event combination) for RT for younger and older adults.

	dfs	Young			Old		
		F	p	η^2	F	p	η^2
TD	1, 9	2.1	0.17	0.194	0.5	0.47	0.058
FP	1, 9	7.5	0.023	0.455	1.8	0.21	0.167
Frequency	1, 9	23.7	0.001	0.725	0.7	0.42	0.07
TD*FP	1, 9	0.0	0.88	0.002	10.1	0.01	0.529
TD*frequency	1, 9	0.1	0.77	0.01	0.0	0.82	0.006
FP*frequency	1, 9	10	0.011	0.528	1.5	0.24	0.146
TD*FP*frequency	1, 9	2	0.19	0.182	0.0	0.93	0.001

$F(1, 9) = 1.8$, $p = 0.212$. However, there was a significant interaction between foreperiod and temporal distance for older adults, $F(1, 9) = 10.1$, $p = 0.011$, due to a stronger foreperiod effect for the long temporal distance condition only. No other interactions were significant (see Table 3).

A mixed analysis of variance (ANOVA) on the error rates did not show a significant main effect for group, $F(1, 18) = 2.71$, $p = 0.117$, speaking against a potential explanation in terms of reduced pattern recognition abilities in older adults. There was a marginal tendency, $F(1, 18) = 3.9$, $p = 0.063$, toward an interaction between group, temporal distance, foreperiod and frequency. However, no other interactions were significant (see Table 2).

In order to specify this tendency, we conducted separate analyses of variance (ANOVA) for group. We observed that the interaction between foreperiod, frequency and temporal distance was significant for older adults, $F(1, 9) = 7.2$, $p = 0.025$. No other interactions were significant (see Table 4). The separate analysis of variance for temporal distance condition in the old group revealed a significant interaction between foreperiod and frequency in the long temporal distance condition, $F(1, 9) = 7.1$, $p = 0.025$, but not in the short temporal distance condition $F(1, 9) = 1.5$, $p = 0.25$.

This interaction was mainly due to the fact that the older adults responded less accurately to the frequent combinations than to infrequent combinations at the long foreperiod in the long temporal distance condition, $t(9) = 2.21$, $p = 0.054$. This means that older adults showed a marginal expectancy effect in the opposite direction at the long foreperiod in the long temporal distance condition.
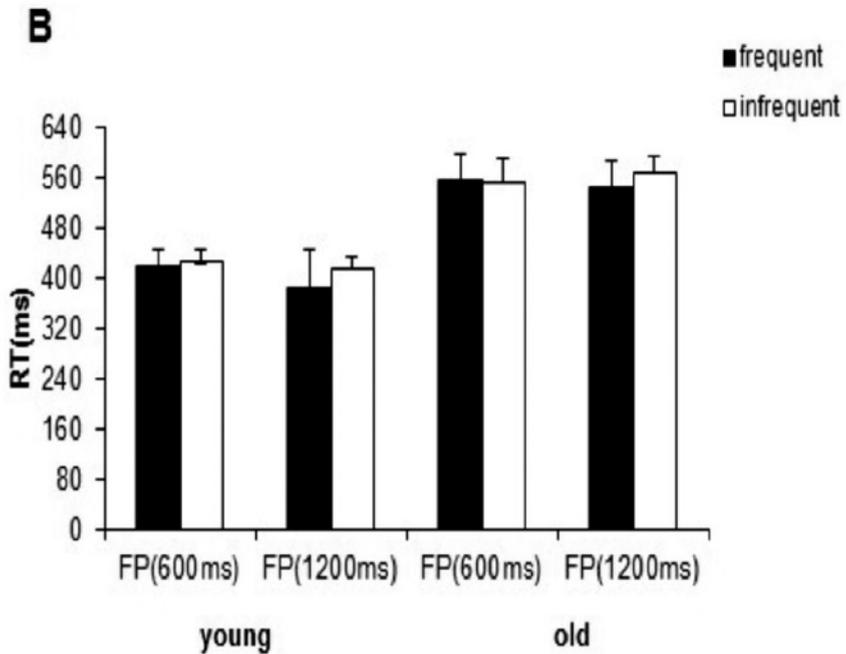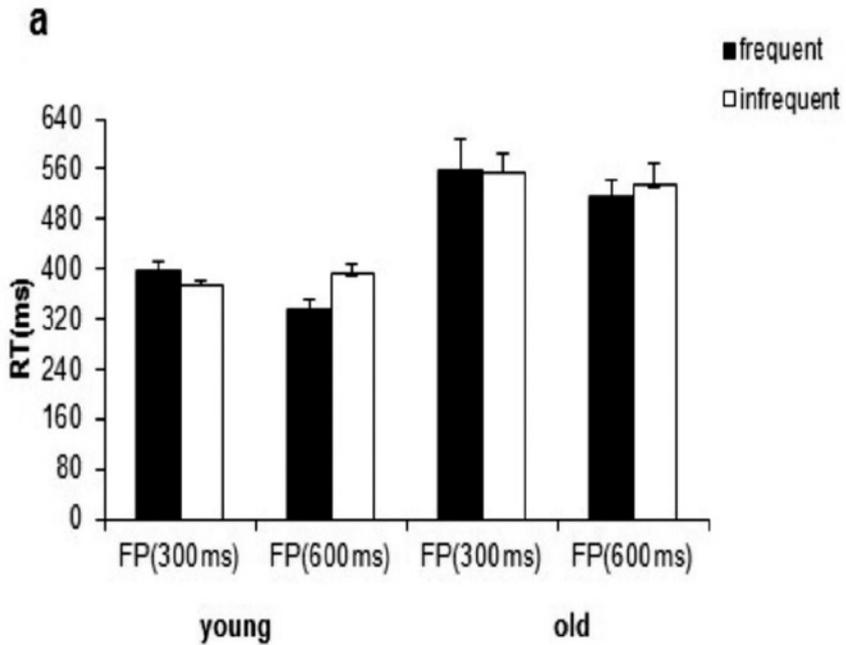
Figure 2. Mean response times (RTs) for all foreperiods, conditions and groups (block 4). Error bars represent the standard error of the mean: (A) shows the mean RTs for the short temporal distance condition; (B) shows the mean RTs for the long temporal distance condition.
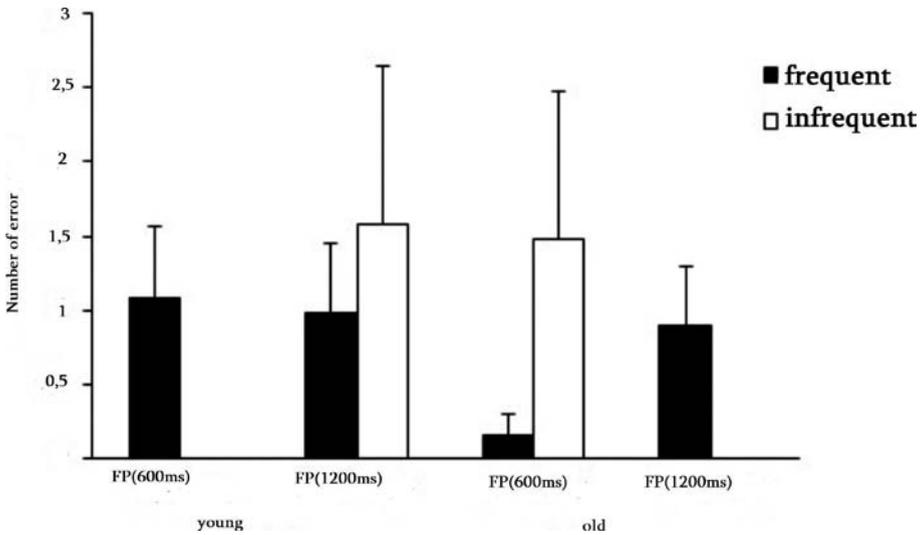
Figure 3. Mean error rates for the long temporal distance condition (block 4). Error bars represent the standard error of the mean.

Table 4.

Separate analysis of variance (ANOVA within-subjects factors of temporal distance (TD, short vs. long), foreperiod duration (short vs. long), and frequency (frequent vs. infrequent foreperiod–event combination) for error rate for older and younger adults.

	dfs	Young			Old		
		F	p	η^2	F	p	η^2
TD	1, 9	2.22	0.17	0.198	0.0	0.98	<0.01
FP	1, 9	0.04	0.84	0.005	0.0	0.91	0.001
Frequency	1, 9	1.35	0.28	0.13	0.1	0.77	0,01
TD*FP	1, 9	0.73	0.4	0.07	1.1	0.313	0.113
TD*frequency	1, 9	1.7	0.22	0.159	0.1	0.76	0.011
FP*frequency	1, 9	0.08	0.77	0.009	0.2	0.61	0.02
TD*FP*frequency	1, 9	0.73	0.42	0.075	7.2	0.025	0.445

4. Discussion

In this study, we compared the ability to form time-based event expectancies between older adults, aged 60–73 years, and young adults, aged 20–32 years, by using a binary choice response task with two different pre-target intervals (short and long foreperiods). In this task participants had to indicate the left or right direction of a target stimulus, which was predicted by the duration of the foreperiod

with 80% validity. All participants completed two experimental conditions with long and short temporal distance between two foreperiods. We found that in both conditions younger adults responded faster to frequent combinations than to infrequent combinations, suggesting that the young participants formed time-based event expectancy. However, this effect was no longer statistically significant for older adults, indicating that formation of time-based event expectancy declined for older adults. In younger adults the time-based event expectancy was more pronounced, with longer intervals. This later finding replicates our previous findings with young adults (e.g., Thomaschke et al., 2015). However, older adults showed a marginal opposite expectancy effect at long foreperiod, i.e., older adults responded less accurate at the frequent combinations than to the infrequent combination, at least in the long temporal distance condition. This also suggests decline of time-based event expectancy for older adults.

One potential explanation for the observed decline in time-based expectancy could be a general reduction of processing speed in older adults. Salthouse (1996), for instance, argued that many age-related reductions of cognition are due to a lengthening of cognitive processes. Necessary cognitive processing steps often run out of time limits required by the current situation, leading to cognitive errors. It might be that the formation of time-based expectancy is among these time-critical mechanisms. When the storage of time-direction associations in memory takes longer for older adults, it might be that this process in many instances is not terminated when the cognitive system gets engaged by the next processing demand: responding to the carrot direction and monitoring the next interval. One strategy for explicitly testing this explanation could be replicating the study with additional non-predictive inter-trial-intervals, to separate successive cognitive demands from each other.

In addition, we found that younger adults responded faster to the long intervals, indicating a stronger variable foreperiod effect (Los & Van den Heuvel, 2001; Los et al., 2001; Steinborn et al., 2008, 2009). Older adults also showed the variable foreperiod effect in long temporal distance condition, suggesting that they were able to estimate the temporal durations. However, older adults did not show the time-based event expectancy effect at all. It seems that this group had difficulty anticipating the event (i.e., carrot direction) based on the foreperiod duration, but were able to use conditional probability strategy (i.e., if carrot does not appear after a short foreperiod, it should appear after a long foreperiod), at least in long temporal condition. It seems like the age-related differences in time-based event expectancy were due to temporal expectation deficits rather than to general timing deficits.

Expectation deficits in aging are well known from other studies as well (see Introduction). Zanto et al. (2011) showed that older adults benefit less than younger adults from predictive knowledge on temporal cued RT tasks such as detection, forced-choice discrimination, and go/no-go discrimination tasks; they also showed age-related alterations in two neuronal markers of expectation

(contingent negative variation and alpha modulation during foreperiod), suggesting temporal expectation deficits in aging. Studies using the RT task with a variable foreperiod showed a reduction of preparation for the shortest interval in older adults compared to younger ones (Bherer & Belleville, 2004a, 2004b), suggesting temporal preparation and temporal probability may be impaired in older adults. Interestingly, in both studies by Bherer & Belleville (2004a, 2004b), increasing the probability of the shortest preparation interval led to equivalent preparatory effects in older and younger adults, suggesting that time uncertainty affects age-related differences in response preparation (Bherer & Belleville, 2004a, 2004b). However, in our study, although the direction of a target stimulus was predicted by the duration of the foreperiod with 80% probability, the older adults were not able to do so from time-based expectancies. It should be noted that Bherer & Belleville (2004a) used two duration windows: short (1000 ms–5000 ms) and long (5000 ms–9000 ms), which were longer than the intervals we used in the present study (i.e., 300 ms–600 ms for the short condition and 600 ms–1200 ms for the long condition). It might be that the temporal windows we used in our study were too short to form time-based expectancies in older adults. Therefore, we recommend that future studies on time-based expectancy in older adults also employ longer FPs with a longer temporal distance than the ones we used in the present study.

Another potential interpretation would propose that time-based expectancy is an even more sensitive measure for the effects of cognitive decline than the conventional variable-foreperiod paradigm (e.g., due to fatigue, cf. Langner et al., 2010, 2011), due to its stronger focus on stable (vs. transient) anticipatory representations and its greater statistical power (embedded in the design).

Our findings could alternatively be explained by an age-related reduction of attentional capacities (Bastin & Meulemans, 2002). Age-related deficits in attention have previously been shown to have an effect on time perception in older adults. Lamotte and Droit-Volet (2017), for example, showed a strong association between the variability of time judgment and attention in older adults, suggesting that age-related differences in time sensitivity could be due to decreasing attention capacities in aging. Bherer, Desjardins, and Fortin (2007), using a time production task with breaks, found that increasing the delay before the break occurrence affected older participants more than younger ones, suggesting that increasing the attentional demands in the timing task was responsible for the differences in timing ability between older and younger adults (see also Bherer at al., 2007). However, the formation of the time-based event expectancies requires us to orient our attention to certain events in specific points of time. Thus, age-related differences in time-based expectancies, as observed in our study, may also be due to a decline in attentional capacities in older participants.

In summary, we found that time-based event expectancies decline during aging, a phenomenon that may be related to general expectation deficits or to a

decline in attentional capacities. However, our study had limitations related to small sample size. Further research is required to better understand the effects of aging on time-based event expectancies, and to more explicitly study the relationship between time-based event expectancies with other cognitive functions such as attention and general expectation.

Acknowledgment

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