The Effect of Anxiety on Time Interval Estimation Ability of Adolescents

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Abstract

Time perception is a complex cognitive function deeply intertwined with daily life. A wide range of factors, including anxiety, influence temporal processing. Over the last few decades, anxiety levels, especially in adolescents, have increased significantly, which may impact their time perception ability. This study investigates the effect of state-anxiety on time perception in adolescents. Forty high school students first completed the State-Trait Anxiety Inventory (STAI-S); participants with a score of 40 or higher were labeled anxious (A) (N=19), and those with a score of 39 or lower were labeled non-anxious (NA) (N=21). They then completed time reproduction tasks of three intervals (500, 1000, and 1500 ms). We hypothesized that state anxiety would negatively correlate with time interval estimation ability in adolescents. The mean absolute error (AE) and mean relative error (Ratio) were calculated to assess temporal performance. A t-test for two independent means was used to calculate the differences between the mean AE of anxious and non-anxious participants. Anxious participants significantly overestimated the 1500 ms interval compared to non-anxious participants, but no significant differences were observed in the 500 ms or 1000 ms intervals. The combined average of the three intervals revealed a significant difference between A and NA participants. Because aging influences time perception, anxiety may affect the time perception of adolescents and adults differently. Differences in methodologies make comparisons to other research examining time reproduction difficult. Time reproduction tasks may be an objective measure of anxiety in adolescents.

INTRODUCTION

Time perception is deeply rooted in virtually all aspects of life. For example, to ensure smooth conversations during social interactions, people observe the pace of the conversation to judge when to speak or when to listen. Similarly, when commuting, people estimate how long it will take to arrive at their destination so that they arrive on time. In sports, athletes rely on their time estimation ability to make split-second decisions: for instance, soccer players need to estimate how long the ball will take to reach them to time their strike for the best shot. Additionally, when playing instruments, musicians must use their perception of time to play their instruments at varying intervals over an extended period. Time perception is even present during sleep: the internal process of the circadian rhythm influences the perception of time by regulating feelings of wakefulness and tiredness.

As exemplified above, time and time perception are seen throughout daily life. However, the concept of time and its relationship with time perception is complex. Time exists in a wide range of intervals, from milliseconds to hours, and while time itself is objective, an individual's perception of time is not. Furthermore, there isn't a single organ or a single pathway dedicated to time perception (1). Rather, multiple brain regions work together to control time perception, and its exact neural mechanism remains unclear (2;3). Consequently, these complexities make understanding the factors that influence the perception of time an important endeavor.

To conceptualize how humans perceive time, many studies reference the pacemaker-accumulator model, which is made up of the clock, memory, and decision stage (4). Inside the clock stage, there is a pacemaker, an accumulator, and a switch. The pacemaker acts like a metronome, emitting regularly spaced pulsations, which are quantified by the accumulator. The switch turns the accumulator on and off; the length of the perceived interval is determined by the total number of pulses counted during that period. In the memory stage, this perceived duration is stored in working memory so that in the decision stage, it can be compared to reference memories to determine the subjective length of the perceived interval (4). In a variation of this model of time perception (5), the pacemaker does not emit pulses independently; instead, it receives direct input from the arousal center, which itself is influenced by external events. For example, a stressful situation may heighten an individual's arousal level, which will speed up the pacemaker rate, lengthening the perceived duration of the situation. In the attentional-gate model (6), a "gate" is added between the pacemaker and the accumulator. When more attention is allocated to temporal processing, the gate widens, enabling more pulses to reach the accumulator. On the contrary, the gate narrows when less attention is allocated, meaning the number of pulses that reach the accumulator is comparatively diminished (6).

Researchers have used various temporal tasks in time perception research. These tasks can first be categorized into retrospective and prospective paradigms. In a retrospective paradigm, participants learn that they need to judge the interval of time only after the presentation of the interval, and performance depends on memory processes. Conversely, subjects in a prospective paradigm are aware of their task prior to the presentation of the interval, and performance depends on attention allocation and arousal level (7).

Some of the most common prospective temporal judgment tasks are verbal estimation, time production, and time reproduction tasks. In a verbal estimation task, participants experience an interval and estimate the duration of the interval before verbally reporting their estimation. In a time production task, subjects are given a specific interval and are required to produce the specified interval (8). In these two tasks, participants employ their long-term memory and verbal processing skills to accurately estimate the time intervals (9). Thus, these two tasks are often used to investigate individual differences related to the internal clock. In a time reproduction task, the participants experience an interval and subsequently replicate the interval. Conceptually, when doing this task, participants go through two phases: the encoding phase, where they experience the interval, and the reproduction phase, where they reproduce the interval. In this task, participants' attention and working memory are at work as they must actively refer to their reference memories and use them to reproduce the interval accurately (9).

An individual's subjective interpretation of time is malleable and easily influenced by a variety of factors. One such factor is musical training. Playing music demands the careful coordination of multiple interconnected actions, including timing, sequencing, and spatial organization (10). Therefore, musicians spend hours honing their sense of rhythm, which has been shown to correlate positively with time interval reproduction accuracy (11). Yun (unpublished) explored the effect of musical training on time interval estimation ability in adolescents (12). The participants first completed a questionnaire regarding their musical training history. If the participants indicated that they've regularly played an instrument for more than three years, they were labeled as musicians. Then, they performed a time interval reproduction task, where four tones were played at equal intervals, and the participants pressed a button indicating when they thought the fifth tone would occur. Utilizing seven intervals ranging from 45 to 120 beats per minute (bpm), the participants reproduced each interval three times for a total of 27 times. The results showed that, on average, musicians were more accurate at estimating time intervals than non-musicians, with an average estimation error of 0.139 seconds for musicians and 0.178 seconds for non-musicians.

Kim (unpublished) conducted a pilot study that was very similar to that of Yun (unpublished) (13). Keeping virtually everything else the same, the number of intervals was shortened to three (45, 95, 120 bpm), and the definition of musician was widened to include anyone who currently plays an instrument or sings at least once a week. The data showed no statistical significance, indicating that there was no relationship between musical training and time interval estimation ability. The difference between Kim and Yun may be attributed to the wider definition of musicians (13).

Other factors influencing time perception include threatening stimuli, such as intimidating faces; previous research has shown that people perceive the duration of angry facial expressions to be longer than neutral facial expressions (14). In addition, those who have had life-threatening experiences say they have perceived time moving slowly during those moments (15). Furthermore, injuries, diseases, and disorders of the brain also distort time perception. Depressed patients, for instance, often experience a subjective slowing of time compared to the general population (16). Also, traumatic brain injury and Parkinson's disease patients, who have impaired cognitive functioning, display temporal dysfunction (17).

As conceptualized by the attentional-gate model, attention influences time perception; when less attention is devoted to time perception, the gate narrows, and fewer pulses pass through it, making it harder to make accurate temporal judgments (6). This explains why time seems to pass more quickly when engaging in an attention-demanding task and why time seems to pass more slowly when attention is allocated to temporal judgment (18). Interestingly, a factor that impairs attention and therefore time perception is anxiety. Although some studies have found that anxiety shortens perceived intervals, others have found that anxiety elongates or has no significant effects on perceived intervals (19;20;21). Bar-Haim et al. (2010) had anxious adults perform a time reproduction task with 2, 4, and 8-second intervals. Compared to controls, anxious patients tended to overestimate the 2-second interval range, while there were no significant differences in the 4 and 8-second intervals. In contrast, although Mioni (2016) employed the same temporal task and intervals of similar length (0.5, 1, and 1.5 seconds), the results showed that anxious adults underestimated the intervals. While both studies investigated anxiety's effect on time perception, they produced contradictory findings. Moreover, the research participants in previous studies only consisted of adults and not adolescents, leaving a gap in understanding how time perception in adolescents may be affected.

In the 21st century, teens are more stressed than ever. In the most recent years, due to the COVID-19 pandemic, the proportion of anxious adolescents reached 19%, almost double the proportion prior to the pandemic (22). These intriguing statistics make investigating anxiety in adolescents more important than ever, as various aspects of their lives may be adversely influenced without their knowledge. Therefore, this study investigates whether time perception is altered in anxious adolescents. Building on previous research, we hypothesized that state anxiety would negatively correlate with time interval estimation ability in adolescents. Results showed that time reproduction ability in adolescents may be affected by anxiety level. Moreover, many of the participants, regardless of anxiety level, tended to overestimate time intervals, though this may be due to the modality effect. Results indicate that time reproduction tasks could be an objective measure to assess anxiety level in adolescents.

MATERIALS AND METHODS

Subjects:

Forty high school students, ages 14 to 18, participated in the study. Participants were recruited from Shattuck-St. Mary's School in Faribault, Minnesota. Before the experiment, the researcher reviewed the consent form with each participant.

Procedure:

Participants were seated in a quiet room with an Asus ROG Zephyrus G14 laptop (14" display and 120 Hz) with the volume set to 18% and a pair of AILIHEN A8 wired headphones on top of the desk in front of them. To assess their anxiety level, participants were first instructed to complete the Spielberger State-Trait Anxiety Inventory (STAI) on the laptop (23). The STAI has two subscales for anxiety, the Trait Anxiety Scale (STAI-T) and the State Anxiety Scale (STAI-S). The STAI-T measures a person's general susceptibility to anxiety, while the STAI-S measures a person's current and temporary feelings of anxiety. In the present study, only the STAI-S was used as this study investigates the relationship between time perception and current, induced feelings of anxiety. The STAI-S was re-created and administered on SurveyMonkey, an online survey platform. Based on the participants' STAI scores, they were divided into anxious and non-anxious groups. Participants were placed into the anxious group if their STAI score was 40 or higher (N=19), and they were placed into the non-anxious group if their score was 39 or lower (N=21). Next, participants, using the laptop, performed the time reproduction task, which was created and administered on PyCharm, an integrated development environment for programming in Python. The code for the time reproduction task can be downloaded from GitHub (https://github.com/justinkimssm/Time-reproduction-task). In the reproduction task, five empty intervals – silent durations marked by auditory signals at the beginning and end – of the same length were played, and the participants attempted to estimate the duration of the 6th interval by pressing the enter key on the laptop. Three intervals – 500, 1000, and 1500 milliseconds – were played, and each interval was randomly presented four times for a total of twelve trials. Throughout the task, the participants heard the auditory signals through the AILIHEN A8 wired headphones, which they were allowed to keep after the study. Before the task, the participants, under the researcher's supervision, were given two practice trials at 750-millisecond intervals to clarify instructions and familiarize themselves with the task. The researcher was not present in the room while participants completed the STAI-S and the time reproduction task.

Statistical analysis:

The participants' temporal performances were analyzed in terms of absolute error (AE) and relative error (Ratio) (21). AE was calculated by taking the absolute value of the difference between their time reproduction and the target duration and then dividing it by the target duration. A greater AE means that their time reproduction was further from the target duration, indicating a lower time perception ability. The Ratio was calculated by dividing their time reproduction by the target duration. The Ratio shows the direction of estimation, with a value of exactly 1 indicating a perfect estimation, a value above 1 indicating an overestimation, and a value under 1 indicating an underestimation.

For each participant, the mean AE was calculated for each of the three intervals (500 ms, 1000 ms, and 1500 ms). The combined average AE was also calculated by taking the average of the three mean AEs. A t-test for two independent means was used to calculate the differences between the mean AEs of the anxious and non-anxious groups.

RESULTS

	500 ms		1000 ms		1500 ms*		Combined Average*	
	Anxious	Non-anxious	Anxious	Non-anxious	Anxious	Non-anxious	Anxious	Non-anxious
Absolute Error	0.251	0.191	0.239	0.181	0.170	0.106	0.220	0.159
t-value	1.516		1.344		2.279		2.027	
p-value	0.069		0.093		0.014		0.025	

Table 1: Absolute error in time intervals of anxious and non-anxious adolescents. Absolute error, determined by taking the absolute value of the reproduction minus the target duration, divided by the target duration, was used to compare responses of anxious and non-anxious participants across three intervals (500 ms, 1000 ms, and 1500 ms) and the combined average of the three intervals.

	500 ms	1000 ms	1500 ms
Mean AE of all participants	0.220	0.209	0.136

Table 2: Mean absolute error (AE) of all participants. Absolute error is abbreviated to AE. This table shows the average absolute error of all participants in 500 ms, 1000 ms, and 1500 ms time intervals.

To assess the anxiety level of participants, the State-Trait Anxiety Inventory (STAI) was used (23). They were labeled anxious if their score was 40 or above and non-anxious if their score was less than 40. To determine time perception ability, all participants completed a time reproduction task at 500 ms, 1000 ms, and 1500 ms four times each, for a total of twelve trials. The temporal performances of participants were analyzed in terms of absolute error (AE) and relative error (Ratio), where AE equals to the absolute value of the difference between time reproduction and the target duration divided by the target duration, and Ratio equals to the time reproduction divided by the target duration.

The mean AE of anxious and non-anxious participants for each interval is reported in **Table 1**. At every interval, as well as the combined average, the mean AE of anxious participants was greater than that of non-anxious participants. The mean AE of anxious adolescents was significantly greater than that of non-anxious adolescents in the 1500 ms interval and the combined average (p = 0.014, p = 0.025, two-sample t-test, **Table 1**). However, the 500 ms and 1000 ms intervals revealed no significant differences between the time estimation abilities of anxious and non-anxious adolescents (p = 0.069, p = 0.093, two-sample t-test, **Table 1**).

The mean AE of all participants across the three intervals is displayed in **Table 2**. It shows that as the interval length increased, the AE of participants decreased. Furthermore, an analysis of relative error (Ratio) revealed that most participants, regardless of anxiety level, tended to overestimate all three intervals. Indeed, on average, 34 out of 40 subjects overestimated the intervals. No within-group comparisons were calculated in this study.

DISCUSSION

The present study shows that anxious participants were generally more inaccurate in time reproduction compared to non-anxious participants across all intervals, most significantly in the 1500 ms interval. Specifically, anxious participants significantly overestimated the 1500 ms interval compared to the non-anxious participants; however, no significant differences were observed in the 500 ms and 1000 ms intervals between anxious and non-anxious participants. Although two of the three individual intervals showed no statistical significance, the combined average of the three intervals was statistically significant. This may be attributed to the fact that the p-values of the 500 ms and 1000 ms intervals, 0.069 and 0.093, respectively, were fairly close to 0.05. It was also found that as the interval length increased, the reproduction accuracy of all participants increased.

Bar-Haim et al. (2010) found similar results: anxious participants significantly overestimated the 2-second (2000 ms) interval compared to non-anxious participants (19). Although Bar-Haim et al. (2010) used a different set of intervals (2000 ms, 4000 ms, and 8000 ms), the fact that statistical significance was achieved in the 1500 ms interval in the present study and the 2000 ms interval in Bar-Haim et al. (2010) is intriguing since the two intervals only differ by 500 ms.

The overestimation of the intervals by anxious participants agrees with the current understanding of the mechanisms underlying prospective time estimation. Previous research has shown that high levels of arousal are associated with anxiety and that estimations of intervals under 2 to 3 seconds are mostly affected by arousal level (19). Taking previous research into account, the attentional model can be used to support this observation. According to the model, during time estimation, anxious participants will have a heightened level of arousal, which will stimulate the pacemaker, increasing the rate at which it produces pulses. As more pulses reach the accumulator over a shorter period of time, the subjective length of the interval will increase, leading to overestimation.

In Lueck (2007), anxious and non-anxious participants, after watching an 8-minute 58-second video, were asked to provide a written estimation of the duration of the video. The researcher found no significant differences between the time estimation abilities of anxious participants and non-anxious participants (20). However, Lueck's participants performed a written estimation in a retrospective paradigm, meaning that the participants learned that they would need to judge the time interval only after the presentation of the interval and that they physically wrote down their time estimations. On the other hand, participants of the present study performed a time reproduction task in a prospective paradigm, meaning that they knew they had to estimate a time interval before the presentation of the interval and that they pressed a button to estimate the time interval.

The present study's results differed from Mioni (2016) when comparing anxious participants to controls. Mioni (2016) found that anxious participants were less accurate than non-anxious participants at 500 ms but found no differences in 1000 ms and 1500 ms intervals (21). However, in the present study, anxious participants were less accurate with the 1500 ms interval and didn't show any difference from non-anxious participants in the 500 ms or 1000 ms intervals. A possible explanation for this difference is how anxiety was scored. In the present study, participants were labeled anxious if their STAI score was 40 or higher, regardless of gender. However, the cut-off scores in Mioni (2016) were relatively higher and differed based on gender, with a cut-off score of 51 or higher for men and 58 or higher for women.

Furthermore, although participants in Mioni (2016) generally underestimated the three intervals, most participants in the present study overestimated them (21). Although the age range of the participants isn't explicitly stated in Mioni (2016), it can be assumed that the participants were adults. Further research is needed to identify exactly how aging affects time perception; however, previous research has found that time perception ability changes as people mature (24). In addition, it's also been shown that emotions have a greater effect on the time perception ability of older adults (25). Thus, the age difference of participants may be a possible explanation for why participants of Mioni (2016) generally underestimated intervals and why participants of the present study generally overestimated them.

A closer examination of Mioni (2016) reveals key methodological differences from the present study. One notable difference is the use of different modalities: while Mioni (2016) employed a visual modality, the present study used an auditory modality (21). This distinction may have influenced the participants' time perception due to the modality effect, the phenomenon where the duration of the perceived time interval varies depending on the type of sensory modality in which the interval is presented. Previous research has shown that people tend to perceive auditory modalities to be longer than visual modalities (26;27). Thus, the modality effect may provide further explanation for the difference in results.

Mioni (2016) observed that participants, regardless of anxiety level, were less accurate when the interval was 500 ms compared to 1000 ms and 1500 ms (21). Likewise, in the present study, as interval length increased, the average AE of all participants decreased, suggesting that the time perception ability of participants improved as duration increased, which does not align with the current literature. According to previous research, longer intervals of time require more attention, and since anxiety reduces attention, time perception ability should decrease as interval length increases (28). Based on the current literature, there is no explanation for this result.

Methodological differences in time perception research make it difficult to make direct comparisons between studies. To confirm the accuracy of the present study's results, future research should be conducted with a greater number of participants. In addition, response bias may have affected the results since the STAI, a self-reported survey, was the only tool utilized to define anxiety level. Thus, employing multiple tools to measure and confirm participants' anxiety levels will enhance the accuracy of the results. Furthermore, as the current study's participants consisted of high school students from ages 14 to 18, future research may examine younger or older participants; comparisons between a wide range of age cohorts may reveal valuable insights into how aging affects time perception. To determine a more objective measure of stress and anxiety, future researchers may examine the relationship between time perception ability and a physiological measure of anxiety, such as cortisol level. Finally, exploring the modality effect in adolescents, specifically between visual and auditory modalities, could offer a greater understanding of adolescents' time perception ability.

The present study found significant differences between the time estimation abilities of anxious and non-anxious adolescents in the 1500 ms interval and the combined average, but found no significant differences in the 500 ms and 1000 ms intervals. However, the relatively low p-values of the 500 ms and 1000 ms intervals are intriguing, and further research is needed to verify the findings of this study. Results suggest that time reproduction tasks could be used as an objective measure of anxiety. Furthermore, our findings contribute to a better understanding of how anxiety can affect adolescents.

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