

The Effect of Joint Action Context on Individual Time Perception

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Abstract

Previous research has predominantly investigated the sources of temporal perception bias at the individual level, yet few studies have examined the mechanisms underlying temporal perception bias in social contexts. The present study integrates a joint action scenario with the temporal bisection task paradigm to systematically investigate the mechanisms through which joint action contexts influence individual temporal perception. Experiment 1 revealed that, compared to the solo condition, the point of subjective equality (PSE) for longer durations in the joint condition significantly shifted toward the companion's short-duration task interval (i.e., the PSE decreased), and temporal perception sensitivity declined significantly. Experiment 2 manipulated belief to elicit shared representation and attenuated social facilitation intensity through the companion's absence. Results demonstrated that, relative to the solo condition, individuals in the belief condition exhibited a PSE shift analogous to that observed in the joint condition, yet temporal perception sensitivity remained unchanged. Experiment 3 manipulated the companion's task goal to a non-temporal-estimation task to diminish the influence of shared representation, while simultaneously manipulating the companion's presence to elicit social facilitation. Results indicated that, compared to the solo condition, individuals' temporal perception sensitivity decreased significantly, but the PSE showed no significant shift. In summary, in joint action contexts, individuals represent the companion's temporal task information via a shared representation mechanism, thereby inducing a shift in time estimation; conversely, when others are present competing for attentional resources, individuals' temporal perception sensitivity is significantly reduced.

Full Text

The Effect of Joint Action Contexts on Individual Time Perception

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Abstract

Previous research has primarily investigated the sources of time perception bias at the individual level, yet few studies have examined the mechanisms underlying time perception bias in social contexts. The present study integrated joint action scenarios with the temporal bisection task paradigm to systematically investigate how joint action contexts influence individual time perception. Experiment 1 revealed that, compared to individual contexts, the point of subjective equality for longer durations shifted significantly toward the partner's shorter duration task interval (i.e., decreased point of subjective equality), and time perception sensitivity decreased significantly in joint contexts. Experiment 2 manipulated belief to activate co-representation and reduced social facilitation intensity through the partner's absence. Results showed that, compared to individual contexts, participants in the belief condition exhibited similar shifts in subjective equality points as in joint contexts, but without significant changes in time perception sensitivity. Experiment 3 manipulated the partner's task goal to a non-temporal estimation task to weaken co-representation effects while maintaining partner presence to elicit social facilitation. Results demonstrated that, compared to individual contexts, time perception sensitivity decreased significantly, but subjective equality points showed no significant shift. In summary, individuals in joint action contexts represent their partner's temporal task information through co-representation mechanisms, leading to biased time estimation; when others compete for attentional resources through their presence, individual time perception sensitivity decreases significantly.

Keywords: time perception, joint action, co-representation, social facilitation

Time perception represents a crucial ability for individuals to perceive the temporal properties of external events and adapt effectively to environmental changes (Chambon et al., 2008; Schirmer et al., 2016). In daily life, humans must accurately perceive and estimate event durations. For instance, divers must precisely estimate time after takeoff to ensure proper technique execution and vertical water entry. However, individual time estimation is not perfectly accurate and typically exhibits subjective biases. Therefore, investigating the sources of time estimation bias and improving temporal accuracy holds significant practical importance and remains a central research topic in psychology both domestically and internationally (Li & Huang, 2019; Li et al., 2017; Shi et al., 2013).

Previous research indicates that two primary factors contribute to time perception bias: historical input from external stimuli and individuals' internal attentional resources. The former adopts a Bayesian theoretical perspective, proposing that prior input information influences time perception through central tendency effects and sequential dependence effects (Sadibolova & Terhune, 2022). Central tendency effects refer to the phenomenon where temporal estimates bias toward the mean of the stimulus distribution interval (i.e., the global context), manifesting as overestimation of short durations or underestimation of long durations (Acerbi et al., 2012; Jazayeri & Shadlen, 2010). For example, Jazayeri and Shadlen (2010) required participants to reproduce time intervals across different duration ranges and found that estimated times systematically biased toward the mean of the stimulus interval, demonstrating the central tendency effect, which was stronger for longer duration intervals (Jazayeri & Shadlen, 2010). Sequential dependence effects, conversely, describe how current trial duration estimation is influenced by previous trials (particularly the immediately preceding trial), representing local context effects. For instance, when the previous trial's duration exceeds the current trial's duration, participants tend to overestimate the current trial's duration (Chen et al., 2023; Wang et al., 2023). Additionally, individuals' cognitive states, particularly attentional resources, affect time estimation accuracy. Compared to completing time estimation tasks alone, simultaneous performance of temporal and non-temporal tasks increases estimation error, with this error increasing as non-temporal task difficulty increases or task performance improves (Brown, 1985).

While most prior research has examined time perception bias at the individual level, real-life situations often require time estimation in joint action contexts. Returning to the diving example, synchronized diving demands that two athletes simultaneously estimate movement timing with precision. Either partner's temporal estimation bias can affect the other, increasing the risk of coordination failure. Despite the prevalence of temporal estimation in joint contexts, empirical research on time perception has primarily focused on individual situations, with only limited studies examining how social cues such as facial expressions (Ishikawa et al., 2016), gaze direction (Burra & Kerzel, 2021), and body movements (Nather et al., 2013) influence time perception. However, these studies essentially remain individual-level time perception research and do not genuinely investigate time perception in authentic joint action scenarios. Joint action refers to the process by which individuals coordinate their actions with others to collectively modify the environment in social contexts, representing a prominent topic in cognitive science research. From this perspective, researchers increasingly focus on how individuals represent others' tasks, actions, and their relationship to themselves, and how they adjust their own actions accordingly (Sebanz et al., 2006; Sebanz & Knoblich, 2021).

In joint action, individuals actively adjust their task performance to coordinate with partners to achieve common goals (Vesper et al., 2017; Wang et al., 2020; Shen et al., 2023). Even without shared goals, individuals spontaneously encode task information from their partner's perspective, thereby influencing

their own performance (Song et al., 2020; Atmaca et al., 2011; Guo et al., 2020; Zheng & Wang, 2023). This phenomenon was first discovered in the joint Simon task, which demonstrated that spatial compatibility effects (joint Simon effects) emerged when two participants completed a task together but disappeared when participants performed the task alone (Sebanz et al., 2003). Researchers proposed the co-representation hypothesis, suggesting that individuals represent their partner's task information while encoding their own task information (Sebanz et al., 2003). Subsequent research has validated the co-representation hypothesis across various paradigms and further indicated that represented partner information can be stored in working memory or long-term memory, thereby influencing individual task performance in contexts such as social learning transfer tasks (Milanese et al., 2010), social statistical learning tasks (Zheng & Wang, 2023; Zheng & Wang, 2024a), and joint ensemble coding tasks (Zheng & Wang, 2024b). For instance, in joint ensemble coding tasks, Zheng and Wang (2024b) employed a line orientation ensemble coding task containing two distribution intervals (0° to 90° and 90° to 180°). Participants performed ensemble coding responses for line sets within one distribution interval while ignoring the other, either alone or jointly with another person. Results revealed that participants' ensemble coding responses in joint contexts biased toward their partner's task distribution interval. When the partner's stimulus distribution interval was larger, individuals tended to make judgments of line orientation that were larger than the actual orientation. In contrast, when completing the task alone, participants exhibited unbiased ensemble coding responses. Importantly, this study verified the causal mechanism of co-representation by manipulating intergroup relationships between participants (i.e., ingroup vs. outgroup). Additionally, research indicates that joint action in the same physical space is not a necessary condition for co-representation processing; individuals also represent partner task information when completing tasks through online formats (belief contexts) (Atmaca et al., 2011; Tsai et al., 2008). Further studies demonstrate that perceived others' intentions or task goals can modulate co-representation effects (Hudson et al., 2016; Iacoboni et al., 2005). For example, when partner task stimuli contain multiple attributes (e.g., color and shape), individuals only represent stimulus attributes consistent with the partner's intentions (Zheng & Wang, 2023).

Beyond co-representation effects, individual task performance in joint action contexts may also be influenced by the social cue of another's presence, manifesting as social facilitation effects (Oliva et al., 2017; Ferraro et al., 2011). Social facilitation refers to the positive or negative influence of others' presence or behavior on individual task performance, with the specific effect depending on task characteristics (Zajonc, 1965; Bond et al., 1983; Cottrell et al., 1968). When tasks are simple or highly automated, social presence typically enhances performance; conversely, in complex or difficult tasks, social presence may inhibit performance by diverting attention (Zajonc, 1965; Xu & Song, 2016). Previous research using challenging tasks such as joint Stroop (Huguet et al., 1999), joint visual search (Zang et al., 2022), and joint memory tasks (Zhang et al.,

2020) has consistently found that others' presence competes for limited attentional resources, resulting in poorer task performance (see review by Mnif et al., 2022). Similar to these tasks, time perception is also a challenging cognitive task. Therefore, it is reasonable to hypothesize that partner presence may distract individuals, reduce time perception sensitivity, and manifest as negative social facilitation effects. Beyond behavioral research, previous studies have provided neural evidence for how partner presence influences attentional resource allocation by comparing lateralized EEG components related to attention across different contexts (Kourtis et al., 2014). For example, Kourtis et al. (2014) investigated attentional resource allocation processes across three scenarios: (1) individuals completing unilateral actions alone (e.g., raising a glass with one hand and pretending to toast with a partner); (2) individuals completing bilateral actions alone (e.g., raising glasses with both hands and pretending to toast with a partner); and (3) individuals completing unilateral actions jointly with a partner sitting opposite (e.g., both raising glasses with one hand and toasting together). Results showed that individuals exhibited significant lateralized EEG components when completing unilateral actions alone, indicating attentional allocation to only one side. However, when completing bilateral actions alone, no lateralized components were observed, suggesting attentional allocation to both sides simultaneously. Critically, when completing unilateral actions jointly with a partner, no obvious lateralized components emerged, indicating that others' presence competes for limited attentional resources, causing individuals to distribute attention across both self and other actions.

In summary, the present study combined temporal bisection and joint action task paradigms to examine whether individual time perception is influenced by joint action contexts and to clarify the potential roles of co-representation and social facilitation mechanisms. Experiment 1 investigated the effects of joint action contexts on time estimation by comparing task performance when individuals completed temporal bisection tasks alone (individual context) or with others (joint context). Building upon this, Experiments 2 and 3 systematically examined whether co-representation and social facilitation are key factors underlying joint context effects on time estimation by manipulating the strength of these mechanisms through belief and non-target contexts. Specifically, in Experiment 2' s belief context, participants completed the temporal bisection task alone but were informed that their partner was completing the same task in another space. This manipulation effectively weakened social facilitation effects through the partner' s absence while allowing participants to represent partner task information through belief (co-representation mechanism). In Experiment 3' s non-target context, participants completed the temporal bisection task alongside a partner in the same space, but the partner performed a non-temporal estimation task (e.g., color identification). Contrary to Experiment 2' s manipulation, partner presence still elicited social facilitation effects, but because task goals differed, the influence of co-represented non-temporal task information on participants' time estimation was minimal. Based on these manipulations, we hypothesized that in joint action contexts, individuals represent

partner task information through co-representation mechanisms and integrate it with self-task information to form prior information, thereby causing subjective time estimation to bias toward the partner's temporal interval (i.e., central tendency bias in subjective equality points). Simultaneously, others' presence consumes attentional resources, significantly reducing time perception sensitivity. Furthermore, based on sequential dependence theory in time perception (Wang et al., 2023; Chen et al., 2023), we hypothesized that sequential dependence effects represent a universal characteristic of time estimation, manifesting as current trial duration estimation being influenced by the previous trial, but that this effect would not differ significantly across contexts.

Experiment 1

2.1.1 Participants

This study employed a between-subjects design with two factors: context (individual vs. joint) and task type (long-duration interval vs. short-duration interval). Given the absence of similar previous research, we selected a relatively conservative medium effect size ($f = 0.25$) for sample size calculation. To achieve 80% statistical power at a significance level of 0.05, a minimum of 128 participants was required (Faul et al., 2007). Ultimately, 128 undergraduate or graduate students from Zhejiang Normal University were recruited (mean age = 21.88 years, $SD = 2.23$, including 27 males). This study was approved by the Zhejiang Normal University Ethics Committee. Participants signed informed consent forms before the experiment and received compensation upon completion.

2.1.2 Materials

Stimuli consisting of orange (RGB = 244, 164, 96) and green (RGB = 152, 251, 152) solid circles (radius = 1.4°) were generated using MATLAB and presented on a gray (127, 127, 127) background of a 21-inch LCD monitor (refresh rate = 120 Hz). Participants were seated approximately 60 cm from the screen. Experimental procedures were programmed using the Psychophysics Toolbox for MATLAB.

2.1.3 Procedure

Participants were randomly assigned to either the short-duration interval group or the long-duration interval group. The short-duration interval group was presented with stimuli lasting 400 ms or 1000 ms, while the long-duration interval group received stimuli lasting 1000 ms or 1600 ms. Different duration intervals were indicated by orange or green circles. Additionally, participants in each duration group were randomly assigned to complete the experiment in either the joint context or individual context.

The experimental design comprised two phases: a learning phase and a formal

experimental phase (see Figure 1 [Figure 1: see original paper]). In the joint context learning phase, two participants sat together at a long table approximately 30 cm apart. Both participants received instructions and completed the practice task independently on separate computers. This arrangement ensured that participants in the joint context could clearly perceive their partner's presence while completing the practice phase relatively independently. In the individual context learning phase, a single participant sat alone in front of a computer to complete the practice task. In both contexts, a fixation point appeared on screen for 1000 ms, followed by a solid circle stimulus from the specific duration interval group. For example, participants in the short-duration interval group were shown an orange circle lasting either 400 ms or 1000 ms. After the circle disappeared, participants judged whether the duration was "short" or "long" based on the on-screen prompt "Please judge" and responded by pressing the "1" or "3" key. Following the response or after 2000 ms, feedback on response accuracy was displayed for a random duration between 1000 ms and 1500 ms. To ensure establishment of standard temporal representations, participants had to meet two criteria to complete practice: (1) complete more than 10 practice trials, and (2) achieve 90% or higher accuracy.

After the learning phase, participants entered the formal experimental phase. In the joint context, two participants sat adjacent to each other and used the same computer to complete the experimental task together. In the individual context, a single participant completed the task alone, seated randomly on either the left or right side of the computer screen. In both contexts, a fixation point appeared for 1000 ms, followed by a randomly presented orange solid circle (duration = 400-1000 ms, step size = 100 ms, 7 levels) or green solid circle (duration = 1000-1600 ms, step size = 100 ms, 7 levels). Participants only judged the duration of circles matching the color from their learning phase as "short" or "long" based on established criteria, while circles of the non-matching color required no response. No feedback was provided after responses; instead, an inter-trial interval of 1000-1500 ms blank screen was presented. The formal experimental phase included a small number of practice trials (no more than 10) and 700 experimental trials (2 duration intervals \times 7 stimulus levels, with 50 repetitions per condition). The entire experiment was divided into 5 blocks, with duration interval and color matching counterbalanced across participants.

2.1.4 Data Analysis

Group-level analysis. Following previous research (Zheng & Wang, 2024b), we first conducted group-level analysis to compare central tendency biases across contexts. Specifically, we calculated the proportion of "long" judgments for each test level per participant and then fitted these proportions using a Logistic function based on maximum likelihood estimation (Treutwein & Strasburger, 1999):

$$Q(t) = Q_{\text{inf}} / (1 + \exp(-\alpha * (t - t_{\text{half}})))$$

where Q_{inf} represents the asymptotic maximum value (as $t \rightarrow \infty$), t_{half} is the symmetric inflection point, and α is the time decay constant.

This fitting procedure yielded three key metrics for each participant: point of subjective equality, just noticeable difference, and Weber fraction. The point of subjective equality corresponds to the duration at which the fitted function indicates a 50% probability of “long” judgments, reflecting subjective temporal bias. Just noticeable difference is half the difference between durations corresponding to 75% and 25% “long” judgment probabilities, reflecting absolute sensitivity in time perception, with lower scores indicating higher perceptual sensitivity. Weber fraction is the ratio of just noticeable difference to point of subjective equality, reflecting relative sensitivity in time perception (Vroomen & Keetels, 2010; Yao et al., 2015). Lower Weber fractions indicate higher time perception sensitivity. In this study, all participants’ goodness-of-fit (R^2) exceeded 0.9, indicating excellent model fit and high data stability.

Trial-level analysis. To further investigate sequential dependence effects (i.e., whether current trial responses were influenced by previous trials), we employed generalized linear models to analyze participants’ keypress response data. First, based on response types in the previous trial (trial $t-1$), current trials (trial t) were classified into two categories: “self” trials where participants responded in the previous trial, and “other” trials where participants made no response in the previous trial. We then constructed separate logistic regression models for self and other conditions, using “short” or “long” judgments as the dependent variable and test stimulus duration and previous trial type as independent variables. Finally, to maintain consistency with central tendency bias metrics, we calculated point of subjective equality, just noticeable difference, and Weber fraction for each participant based on the regression model curves.

Null hypothesis testing and Bayesian statistics were both conducted using JASP software (version 0.10.0.0; The JASP Team, 2022). Post-hoc comparison p -values in hypothesis testing were corrected using Tukey’s method, and Bayesian factors were calculated using JASP’s default prior distributions.

2.2.1 Group-level Analysis

Point of Subjective Equality. A 2 (context: individual vs. joint) $\times 2$ (task type: long-duration interval vs. short-duration interval) ANOVA on points of subjective equality revealed a significant main effect of task type ($F(1,124) = 1568.04$, $p < 0.001$, $p^2 = 0.93$, $BF_{inclusion} = \infty$). Points of subjective equality in the long-duration interval condition were significantly larger than in the short-duration interval condition (mean difference = 619.80 ms, 95% CI = [588.82, 650.78], SE = 15.65 ms, $t = 39.60$, $p < 0.001$, Cohen’s $d = 7.00$). The main effect of context was marginally significant ($F(1,124) = 3.58$, $p = 0.061$, $p^2 = 0.03$, $BF_{inclusion} = 2.94$). The interaction between context and task type was significant ($F(1,124) = 6.65$, $p = 0.011$, $p^2 = 0.05$, $BF_{inclusion} = 7.93$). Simple effects analysis showed no significant difference between joint and individual

contexts for the short-duration interval condition (mean difference = 10.74 ms, 95% CI = [-68.39, 46.90], SE = 22.14 ms, $t = 0.49$, $p = 0.962$, Cohen's $d = 0.12$). However, for the long-duration interval condition, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 69.95 ms, 95% CI = [12.31, 127.60], SE = 22.14 ms, $t = 3.16$, $p = 0.011$, Cohen's $d = 0.79$).

Just Noticeable Difference. A 2 (context: individual vs. joint) \times 2 (task type: long-duration interval vs. short-duration interval) ANOVA on just noticeable differences revealed a significant main effect of task type ($F(1,124) = 100.57$, $p < 0.001$, $p^2 = 0.45$, $BFinclusion = \infty$), with larger just noticeable differences in the long-duration interval condition than in the short-duration interval condition (mean difference = 53.85 ms, 95% CI = [43.22, 64.48], SE = 5.37 ms, $t = 10.03$, $p < 0.001$, Cohen's $d = 1.77$). The main effect of context was significant ($F(1,124) = 7.73$, $p = 0.006$, $p^2 = 0.06$, $BFinclusion = 5.30$), with larger just noticeable differences in the joint context than in the individual context (mean difference = 14.93 ms, 95% CI = [4.30, 25.56], SE = 5.37 ms, $t = 2.78$, $p = 0.006$, Cohen's $d = 0.49$). The interaction between task type and context was not significant ($F(1,124) = 0.88$, $p = 0.351$, $p^2 = 0.01$, $BFinclusion = 1.28$).

Weber Fraction. A 2 (context: individual vs. joint) \times 2 (task type: long-duration interval vs. short-duration interval) ANOVA on Weber fractions revealed a significant main effect of duration interval ($F(1,124) = 5.84$, $p = 0.017$, $p^2 = 0.05$, $BFinclusion = 2.32$), with smaller Weber fractions in the long-duration interval condition than in the short-duration interval condition (mean difference = 0.013, 95% CI = [0.002, 0.024], SE = 0.006, $t = 2.42$, $p = 0.017$, Cohen's $d = 0.41$). The main effect of context was significant ($F(1,124) = 11.11$, $p = 0.001$, $p^2 = 0.08$, $BFinclusion = 20.96$), with larger Weber fractions in the joint context than in the individual context (mean difference = 0.019, 95% CI = [0.008, 0.03], SE = 0.006, $t = 3.33$, $p = 0.001$, Cohen's $d = 0.59$). The interaction between task type and context was not significant ($F(1,124) = 0.61$, $p = 0.436$, $p^2 = 0.01$, $BFinclusion = 0.93$).

[Figure 2: see original paper] shows group-level and trial-level analysis results for joint and individual contexts across long- and short-duration interval conditions in Experiment 1. The left panel displays psychometric curves for each condition, with the y-axis representing the proportion of "long" judgments and the x-axis representing different test duration levels. The intersection of the dashed line representing 50% judgment rate with the psychometric curve reflects participants' points of subjective equality across conditions. The right bar graphs sequentially present mean points of subjective equality, just noticeable differences, and Weber fractions across task contexts (individual vs. joint). The upper portion shows group-level analysis results, while the lower portion shows trial-level analysis results. Error bars represent standard error (SE). $p < 0.05$, $p < 0.01$, $p < 0.001$, n.s. indicates $p > 0.05$.

2.2.2 Trial-level Analysis

Point of Subjective Equality. A 2 (context: individual vs. joint) $\times 2$ (task type: long-duration interval vs. short-duration interval) $\times 2$ (previous trial type: self vs. other) repeated-measures ANOVA on points of subjective equality revealed a significant main effect of task type ($F(1,124) = 1536.42$, $p < 0.001$, $p^2 = 0.93$, $BF_{inclusion} = \infty$), with larger points of subjective equality in the long-duration interval condition than in the short-duration interval condition (mean difference = 620.78 ms, 95% CI = [589.44, 652.78], SE = 15.83 ms, $t = 39.20$, $p < 0.001$, Cohen' s d = 6.60). The main effect of previous trial type was significant ($F(1,124) = 41.89$, $p < 0.001$, $p^2 = 0.25$, $BF_{inclusion} = 1.63 \times 10^{11}$), with larger points of subjective equality following self trial than other trials (mean difference = 32.96 ms, 95% CI = [13.81, 52.01], SE = 10.98 ms, $t = 3.00$, $p = 0.007$, Cohen' s d = 0.95). The interaction between context and task type was significant ($F(1,124) = 7.56$, $p = 0.007$, $p^2 = 0.06$, $BF_{inclusion} = 7.55$). Simple effects analysis revealed that for the long-duration interval condition, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 73.86 ms, 95% CI = [13.81, 133.91], SE = 22.40 ms, $t = 3.30$, $p = 0.007$, Cohen' s d = 0.79). For the short-duration interval condition, no significant difference emerged between joint and individual contexts (mean difference = 13.24 ms, 95% CI = [-73.29, 46.82], SE = 22.40 ms, $t = 0.59$, $p = 0.935$, Cohen' s d = 0.14). The interaction between previous trial type and task type was significant ($F(1,124) = 41.55$, $p < 0.001$, $p^2 = 0.25$, $BF_{inclusion} = 5.80 \times 10^6$). Simple effects analysis showed that for the long - duration interval condition, points of subjective equality were significantly lower ($F < 0.01$, $BF_{inclusion} < 0.46$).

Just Noticeable Difference. A 2 (context: individual vs. joint) $\times 2$ (task type: long-duration interval vs. short-duration interval) $\times 2$ (previous trial type: self vs. other) repeated-measures ANOVA on just noticeable differences revealed a significant main effect of task type ($F(1,124) = 95.29$, $p < 0.001$, $p^2 = 0.44$, $BF_{inclusion} = 3.61 \times 10^{13}$), with larger just noticeable differences in the long - duration interval condition than in the short - duration interval condition (mean difference = 12.35 ms, 95% CI = [2.44, 22.27], SE = 5.01 ms, $t = 2.47$, $p = 0.015$, Cohen' s d = 0.35). The main effect of previous trial type was significant ($F(1,124) = 4.22$, $p = 0.042$, $p^2 = 0.03$, $BF_{inclusion} = 0.65$), with larger just noticeable differences following self trials than other trials (mean difference = 7.91 ms, 95% CI = [0.29, 15.53], SE = 3.85 ms, $t = 2.06$, $p = 0.042$, Cohen' s d = 0.221). All remaining interactions were non-significant ($F < 0.05$, $p > 0.824$, $p^2 < 0.01$, $BF_{inclusion} < 0.46$).

Weber Fraction. A 2 (context: individual vs. joint) $\times 2$ (task type: long-duration interval vs. short-duration interval) $\times 2$ (previous trial type: self vs. other) repeated-measures ANOVA on Weber fractions revealed a significant main effect of task type ($F(1,124) = 7.14$, $p = 0.009$, $p^2 = 0.05$, $BF_{inclusion} = 2.36$), with smaller Weber fractions in the long-duration interval condition than in the short-duration interval condition (mean difference = 0.015, 95% CI = [0.004, 0.026], SE = 0.006, $t = 2.67$, $p = 0.009$, Cohen' s d = 0.39). The

main effect of context was significant ($F(1,124) = 9.32$, $p = 0.003$, $p^2 = 0.07$, $BFinclusion = 6.56$), with larger Weber fractions in the joint context than in the individual context (mean difference = 0.017, 95% CI = [0.006, 0.028], SE = 0.006, $t = 3.05$, $p = 0.003$, Cohen's $d = 0.45$). The main effect of previous trial type was not significant ($F(1,124) = 1.79$, $p = 0.184$, $p^2 = 0.01$, $BFinclusion = 0.28$). All remaining interactions were non-significant ($F < 3.49$, $p > 0.064$, $p^2 < 0.03$, $BFinclusion < 0.58$).

2.3 Discussion

Group-level analysis results demonstrated that in joint contexts, individuals' points of subjective equality for long durations significantly shifted toward their partner's temporal interval, manifesting as central tendency bias. Trial-level analysis further confirmed this central tendency bias, which was unaffected by previous trial type. These findings indicate that joint contexts prompt individuals to accumulate prior temporal information related to both their own and their partner's tasks, whereas in individual contexts, participants only accumulate prior information related to their own task. Additionally, both group-level and trial-level analyses showed that time perception sensitivity in joint contexts was significantly lower than in individual contexts, suggesting that joint action contexts influence cognitive states during time perception tasks, reducing accuracy at both global and local levels of duration estimation.

These results support our hypothesis that joint action contexts significantly influence individual time perception, consistent with previous findings on joint action effects on task performance (Sebanz et al., 2006). However, Experiment 1 alone cannot disentangle whether joint context effects operate through co-representation or social facilitation mechanisms. Therefore, to systematically investigate whether co-representation and social facilitation are key mechanisms underlying joint context effects on time estimation and their potential roles, we manipulated the strength of these mechanisms through belief and non-target contexts in subsequent experiments.

Experiment 2

Experiment 1 found that compared to individual contexts, only participants in the long-duration interval group exhibited significantly decreased points of subjective equality in joint contexts. Furthermore, all participants in joint contexts showed reduced time perception sensitivity. To further investigate whether these observed effects were primarily due to co-representation or social facilitation, Experiment 2 employed a belief context. In this context, the partner's absence effectively weakened social facilitation effects, while participants could still represent partner task information through belief (co-representation mechanism). Given that context differences in subjective equality points only emerged in long-duration interval estimation tasks in Experiment 1, Experiment 2 only required participants to complete long-duration interval estimation tasks.

3.1 Participants

To maintain consistency with the number of participants in the long-duration interval group from Experiment 1, Experiment 2 recruited 32 new participants (mean age = 21.58 years, SD = 2.41, including 8 males). All other aspects remained consistent with Experiment 1.

[Figure 3: see original paper] shows schematic diagrams of procedures for Experiments 2 and 3. The left panel illustrates Experiment 2's belief context, while the right panel shows Experiment 3's non-target context. The area above the dashed line represents the learning phase, and the area below represents the formal experimental phase.

3.2 Procedure

Apparatus, procedures, and analysis methods were essentially identical to Experiment 1 (see Figure 3), with the following modifications. To strengthen participants' belief that they were completing the task jointly with a partner during the learning phase and ensure consistency across experimental manipulations, participants in Experiment 2 completed the learning phase adjacent to a confederate. Specifically, similar to Experiment 1's joint context, participants sat with a same-sex confederate at a long table approximately 30 cm apart. Both received instructions and completed practice tasks on separate computers. The experimenter then informed them of their random group assignments for the formal experimental phase (participants were always assigned to the long-duration interval condition) and corresponding task requirements. Subsequently, the experimenter informed them that they would complete the experiment in separate rooms, ensuring participants clearly understood that their partner would be in another room, and asked participants to sit on either the left or right side of the computer screen. For data analysis, we combined participants' data from Experiment 2 with long-duration interval group data from Experiment 1 for cross-experiment analysis.

3.3.1 Group-level Analysis

Point of Subjective Equality. A one-way ANOVA comparing three contexts (individual, joint, and belief) on points of subjective equality revealed a significant main effect of context ($F(2, 93) = 4.87, p = 0.010, \eta^2 = 0.10, BF_{inclusion} = 4.43$). Post-hoc comparisons showed that points of subjective equality in the belief context were significantly lower than in the individual context (mean difference = 57.23 ms, 95% CI = [0.36, 114.10], SE = 23.88 ms, $t = 2.40, p = 0.048$, Cohen's $d = 0.60$), but did not differ significantly from the joint context (mean difference = 12.72 ms, 95% CI = [-69.59, 44.14], SE = 23.85 ms, $t = 0.53, p = 0.855$, Cohen's $d = 0.13$). Consistent with Experiment 1, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 69.95 ms, 95% CI = [13.09, 126.82], SE = 23.88 ms, $t = 2.93, p = 0.012$, Cohen's $d = 0.73$).

Just Noticeable Difference. A one-way ANOVA comparing three contexts on just noticeable differences revealed a significant main effect of context ($F(2, 93) = 4.24$, $p = 0.017$, $p^2 = 0.08$, $BFinclusion = 2.71$). Post-hoc comparisons showed that just noticeable differences in the belief context were significantly smaller than in the joint context (mean difference = 23.44 ms, 95% CI = [2.76, 44.12], SE = 8.68 ms, $t = 2.70$, $p = 0.022$, Cohen's $d = 0.68$), but did not differ significantly from the individual context (mean difference = 3.49 ms, 95% CI = [-17.20, 24.17], SE = 8.68 ms, $t = 0.40$, $p = 0.915$, Cohen's $d = 0.10$). Consistent with Experiment 1, just noticeable differences in the joint context were marginally significantly larger than in the individual context (mean difference = 19.95 ms, 95% CI = [0.73, 40.64], SE = 8.68 ms, $t = 2.30$, $p = 0.061$, Cohen's $d = 0.57$).

Weber Fraction. A one-way ANOVA comparing three contexts on Weber fractions revealed a significant main effect of context ($F(2, 93) = 7.15$, $p = 0.001$, $p^2 = 0.13$, $BFinclusion = 25.54$). Post-hoc comparisons showed that Weber fractions in the belief context were significantly smaller than in the joint context (mean difference = 0.02, 95% CI = [0.005, 0.037], SE = 0.007, $t = 3.10$, $p = 0.007$, Cohen's $d = 0.78$), but did not differ significantly from the individual context (mean difference = 0.002, 95% CI = [-0.018, 0.014], SE = 0.007, $t = 0.33$, $p = 0.943$, Cohen's $d = 0.08$). Consistent with Experiment 1, Weber fractions in the joint context were significantly larger than in the individual context (mean difference = 0.023, 95% CI = [0.007, 0.039], SE = 0.007, $t = 3.43$, $p = 0.003$, Cohen's $d = 0.86$).

[Figure 4: see original paper] shows group-level and trial-level analysis results across contexts in Experiment 2. The upper panel presents group-level results, while the lower panel presents trial-level results. Error bars represent standard error (SE). † $p < 0.1$, $p < 0.05$, $p < 0.01$, $p < 0.001$.

3.3.2 Trial-level Analysis

Point of Subjective Equality. A 3 (context: individual, joint, belief) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on points of subjective equality revealed a significant main effect of context ($F(2, 93) = 5.18$, $p = 0.007$, $p^2 = 0.10$, $BFinclusion = 4.72$). Post-hoc comparisons showed that points of subjective equality in the belief context were significantly lower than in the individual context (mean difference = 59.08 ms, 95% CI = [-0.12, 118.27], SE = 24.28 ms, $t = 2.43$, $p = 0.044$, Cohen's $d = 0.58$), but did not differ significantly from the joint context (mean difference = 14.78 ms, 95% CI = [-44.41, 73.98], SE = 24.28 ms, $t = 0.61$, $p = 0.816$, Cohen's $d = 0.15$). Consistent with Experiment 1, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 73.86 ms, 95% CI = [14.67, 133.16], SE = 24.28 ms, $t = 3.04$, $p = 0.009$, Cohen's $d = 0.72$). The main effect of previous trial type was significant ($F(1, 93) = 89.33$, $p < 0.001$, $p^2 = 0.49$, $BFinclusion = 1.45 \times 10^{12}$), with larger points of subjective equality following self trial than other trials (mean difference = 61.20 ms, 95% CI = [44.41, 77.99], SE = 24.28 ms, $t = 2.52$, $p = 0.012$, Cohen's $d = 0.62$).

= 0.10, $BFinclusion = 0.50$).

Just Noticeable Difference. A 3 (context: individual, joint, belief) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on just noticeable differences revealed no significant main effects or interactions ($F < 2.29$, $p > 0.107$, $p^2 < 0.05$, $BFinclusion < 0.36$).

Weber Fraction. A 3 (context: individual, joint, belief) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on Weber fractions revealed a significant main effect of context ($F(2, 93) = 4.45$, $p = 0.014$, $p^2 = 0.09$, $BFinclusion = 1.85$). Post-hoc comparisons showed that Weber fractions in the belief context were marginally significantly smaller than in the joint context (mean difference = 0.015, 95% CI = [-0.001, 0.032], SE = 0.007, $t = 2.29$, $p = 0.062$, Cohen's $d = 0.45$), but did not differ significantly from the individual context (mean difference = 0.003, 95% CI = [-0.013, 0.02], SE = 0.007, $t = 0.51$, $p = 0.866$, Cohen's $d = 0.10$). Consistent with Experiment 1, Weber fractions in the joint context were significantly larger than in the individual context (mean difference = 0.019, 95% CI = [0.002, 0.035], SE = 0.007, $t = 2.80$, $p = 0.017$, Cohen's $d = 0.55$). Neither the main effect of previous trial type ($F(1, 93) < 0.01$, $p = 0.960$, $p^2 < 0.01$, $BFinclusion = 0.12$) nor its interaction with context was significant ($F(2, 93) = 0.81$, $p = 0.448$, $p^2 = 0.02$, $BFinclusion = 0.07$).

Both group-level and trial-level results from Experiment 2 demonstrated that, compared to individual contexts, individuals' points of subjective equality in the belief context were similar to those in the joint context from Experiment 1, showing significant shifts toward the partner's temporal interval. The belief context (partner absent) effectively weakened social facilitation effects but did not prevent individuals from representing partner task information through belief (Atmaca et al., 2011; Tsai et al., 2008). These results indicate that joint contexts shift subjective equality points by integrating partner task temporal information as prior information through co-representation mechanisms. Conversely, group-level time perception sensitivity analyses showed that sensitivity in the belief context was significantly higher than in the joint context from Experiment 1 and restored to levels comparable to the individual context. Trial-level analysis of Weber fractions showed similar trends. These findings suggest that partner presence (joint context) and the resulting social facilitation effects are the primary cause of decreased time perception sensitivity.

Experiment 3

Experiments 1 and 2 found that points of subjective equality decreased significantly in both joint and belief contexts compared to individual contexts, while time perception sensitivity remained high in individual and belief contexts. Experiment 3 further established a non-target context where partner presence still elicited social facilitation effects, but because the partner's task differed, co-represented non-temporal task information had minimal influence on participants' time estimation. Similar to Experiment 2, Experiment 3 only

required participants to complete long-duration interval estimation tasks.

4.1 Participants

To maintain consistency with the number of participants in the long-duration interval group from Experiment 1, Experiment 3 recruited 32 participants (mean age = 21.58 years, SD = 2.41, including 8 males).

4.2 Procedure

Apparatus, procedures, and analysis methods were essentially identical to Experiment 1, with the following modifications. To ensure consistency in manipulation conditions across experiments, participants in Experiment 3 completed the learning phase adjacent to a confederate. Specifically, similar to Experiment 1's joint context, participants sat with a same-sex confederate at a long table approximately 30 cm apart. Both received instructions and completed practice tasks on separate computers. Unlike Experiment 1's joint context, during the learning phase, participants completed duration judgment tasks while the confederate completed shape judgment tasks, with task stimuli changed from solid circles to same-colored upright or inverted triangles. After the learning phase, participants and confederates sat adjacent to each other and used the same computer to complete the formal experimental phase together. The formal experimental phase presented three types of stimuli: solid circles, upright triangles, and inverted triangles, with colors consistent with the learning phase. In this phase, participants judged the duration of solid circles (consistent with Experiment 1: duration = 1000–1600 ms, step size = 100 ms, 7 levels), while confederates judged the shape of upright or inverted triangles, with stimulus presentation durations matching Experiment 1's short-duration interval (duration = 400–1000 ms, step size = 100 ms, 7 levels). Instructions ensured participants understood their partner's task requirements. Consistent with Experiment 2, we combined data from Experiment 3 participants with long-duration interval group data from Experiment 1 for cross-experiment analysis.

4.3.1 Group-level Analysis

Point of Subjective Equality. A one-way ANOVA comparing three contexts (individual, joint, and non-target) on points of subjective equality revealed a significant main effect of context ($F(2, 93) = 4.56, p = 0.013, \eta^2 = 0.09, \text{BF}_{\text{inclusion}} = 3.47$). Post-hoc comparisons showed that points of subjective equality in the non-target context were significantly higher than in the joint context (mean difference = 70.10 ms, 95% CI = [6.30, 133.91], SE = 26.78 ms, $t = 2.62, p = 0.028, \text{Cohen's } d = 0.65$), but did not differ significantly from the individual context (mean difference = 0.15 ms, 95% CI = [-63.96, 63.65], SE = 26.78 ms, $t = 0.01, p = 1.000, \text{Cohen's } d < 0.01$). Consistent with Experiment 1, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 69.95 ms, 95% CI = [6.15, 133.76], SE = 26.79 ms, $t = 2.61, p = 0.028, \text{Cohen's } d = 0.65$).

Just Noticeable Difference. A one-way ANOVA comparing three contexts on just noticeable differences revealed a significant main effect of context ($F(2, 93) = 3.33$, $p = 0.040$, $p^2 = 0.07$, $BFinclusion = 1.33$). Post-hoc comparisons showed that just noticeable differences in the non-target context were marginally significantly larger than in the individual context (mean difference = 20.44 ms, 95% CI = [1.09, 41.96], SE = 9.04 ms, $t = 2.26$, $p = 0.066$, Cohen' s d = 0.57), but did not differ significantly from the joint context (mean difference = 0.48 ms, 95% CI = [-22.01, 21.04], SE = 9.04 ms, $t = 0.05$, $p = 0.998$, Cohen' s d = 0.01). Consistent with Experiment 1, just noticeable differences in the joint context were marginally significantly larger than in the individual context (mean difference = 19.95 ms, 95% CI = [1.57, 41.48], SE = 9.04 ms, $t = 2.21$, $p = 0.075$, Cohen' s d = 0.55).

Weber Fraction. A one-way ANOVA comparing three contexts on Weber fractions revealed a significant main effect of context ($F(2, 93) = 6.19$, $p = 0.003$, $p^2 = 0.12$, $BFinclusion = 12.26$). Post-hoc comparisons showed that Weber fractions in the non-target context were significantly larger than in the individual context (mean difference = 0.016, 95% CI = [0.0002, 0.032], SE = 0.007, $t = 2.41$, $p = 0.046$, Cohen' s d = 0.60), but did not differ significantly from the joint context (mean difference = 0.007, 95% CI = [-0.009, 0.023], SE = 0.007, $t = 1.01$, $p = 0.573$, Cohen' s d = 0.25). Consistent with Experiment 1, Weber fractions in the joint context were significantly larger than in the individual context (mean difference = 0.023, 95% CI = [0.007, 0.039], SE = 0.007, $t = 3.42$, $p = 0.003$, Cohen' s d = 0.86).

[Figure 5: see original paper] shows group-level and trial-level analysis results across contexts in Experiment 3. The upper panel presents group-level results, while the lower panel presents trial-level results. Error bars represent standard error (SE). $\dagger p < 0.1$, $p < 0.05$, $p < 0.01$, $p < 0.001$.

4.3.2 Trial-level Analysis

Point of Subjective Equality. A 3 (context: individual, joint, non-target) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on points of subjective equality revealed a significant main effect of context ($F(2, 93) = 4.60$, $p = 0.012$, $p^2 = 0.09$, $BFinclusion = 3.12$). Post-hoc comparisons showed that points of subjective equality in the non-target context were significantly higher than in the joint context (mean difference = 67.46 ms, 95% CI = [1.64, 133.27], SE = 26.99 ms, $t = 2.50$, $p = 0.037$, Cohen' s d = 0.60), but did not differ significantly from the individual context (mean difference = 6.40 ms, 95% CI = [-59.41, 72.22], SE = 26.99 ms, $t = 0.24$, $p = 0.969$, Cohen' s d = 0.06). Consistent with Experiment 1, points of subjective equality in the joint context were significantly lower than in the individual context (mean difference = 73.86 ms, 95% CI = [8.05, 139.67], SE = 26.99 ms, $t = 2.74$, $p = 0.020$, Cohen' s d = 0.65). The main effect of previous trial type was significant ($F(1, 93) = 79.31$, $p < 0.001$, $p^2 = 0.46$, $BFinclusion = 1.15 \times 10^{11}$), with larger points of subjective equality following self trials than other trials (mean difference = 62.45 ms, 95% CI = [1.15, 123.75], SE = 26.99 ms, $t = 2.31$, $p = 0.023$, Cohen' s d = 0.55).

= 0.01, $BFinclusion = 0.37$).

Just Noticeable Difference. A 3 (context: individual, joint, non-target) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on just noticeable differences revealed no significant main effects or interactions ($F < 2.20$, $p > 0.117$, $p^2 < 0.05$, $BFinclusion < 0.32$).

Weber Fraction. A 3 (context: individual, joint, non-target) \times 2 (previous trial type: self vs. other) repeated-measures ANOVA on Weber fractions revealed a significant main effect of context ($F(2, 93) = 4.31$, $p = 0.016$, $p^2 = 0.09$, $BFinclusion = 1.46$). Post-hoc comparisons showed that, consistent with Experiment 1, Weber fractions in the joint context were significantly larger than in the individual context (mean difference = 0.019, 95% CI = [0.003, 0.034], SE = 0.006, $t = 2.89$, $p = 0.013$, Cohen' s d = 0.51). Weber fractions in the non-target context showed a similar trend (mean difference = 0.019, 95% CI = [-0.003, 0.028], SE = 0.006, $t = 1.92$, $p = 0.14$, Cohen' s d = 0.34) but did not differ significantly from the joint context (mean difference = 0.003, 95% CI = [-0.013, 0.02], SE = 0.007, $t = 0.51$, $p = 0.866$, Cohen' s d = 0.10). Neither the main effect of previous trial type ($F(1, 93) = 0.07$, $p = 0.800$, $p^2 < 0.01$, $BFinclusion = 0.16$) nor its interaction with context was significant ($F(2, 93) = 0.68$, $p = 0.509$, $p^2 = 0.01$, $BFinclusion = 0.06$).

Both group-level and trial-level results from Experiment 3 demonstrated that, compared to the joint context in Experiment 1, individuals' points of subjective equality in the non-target context were similar to those in the individual context from Experiment 1 and did not significantly bias toward the partner' s temporal interval. Previous research has found that individuals' co-representation of partner task information depends on partner goals (Hudson et al., 2016; Iacoboni et al., 2005). Therefore, the absence of subjective equality point shifts in the non-target context indicates that when partner task goals are unrelated to time, individuals cannot integrate partner task temporal information through co-representation mechanisms to influence their points of subjective equality. Conversely, group-level time perception sensitivity analyses showed that sensitivity in the non-target context was significantly lower than in the individual context and comparable to the joint context. Trial-level analysis of Weber fractions showed similar trends. These results further support Experiment 2' s conclusion that partner presence and the resulting social facilitation effects are the primary cause of decreased time perception sensitivity.

General Discussion

Unlike previous research that primarily investigated time perception bias at the individual level, the present study is the first to combine temporal bisection and joint action task paradigms to systematically investigate time perception bias in joint action contexts, thereby expanding the research contexts for time perception. Building upon this, the present study further clarified the roles of co-representation and social facilitation as potential mechanisms.

Experiment 1 compared differences in time perception processing between individual and joint contexts when completing temporal bisection tasks. Both group-level and trial-level analyses found that only in the long-duration interval condition did points of subjective equality in joint contexts significantly decrease compared to individual contexts, while both just noticeable differences and Weber fractions in joint contexts were significantly higher than in individual contexts. In the short-duration interval condition, joint contexts only significantly increased just noticeable differences and Weber fractions. Additionally, sequential dependence analyses revealed that individuals' time perception was significantly influenced by previous other trials, manifesting as decreased points of subjective equality and increased just noticeable differences. Consistent with our hypotheses, Experiment 1 demonstrated that individuals in joint contexts were influenced by their partners, exhibiting central tendency bias in time estimation. Experiments 2 and 3 further manipulated the strength of co-representation and social facilitation through belief and non-target contexts to systematically investigate whether these mechanisms were critical for joint context effects on time estimation. Experiment 2 found that when co-representation was activated through belief, individuals exhibited points of subjective equality comparable to joint contexts and significantly lower than individual contexts. Meanwhile, weakening social facilitation through partner absence resulted in just noticeable differences and Weber fractions comparable to individual contexts and significantly lower than joint contexts. Conversely, Experiment 3 found that when co-representation was weakened by assigning partners a non-temporal estimation task, points of subjective equality were comparable to individual contexts and significantly higher than joint contexts. Meanwhile, manipulating partner presence to elicit social facilitation resulted in just noticeable differences and Weber fractions comparable to joint contexts and significantly higher than individual contexts. Combined across three experiments, these results indicate that individuals' time perception in joint action contexts is influenced by partners and exhibits different effects based on distinct mechanisms. First, individuals represent partner task information as prior information through co-representation mechanisms, resulting in subjective time estimation biases toward the partner's temporal interval. Second, partner presence elicits social facilitation, consuming attentional resources and thereby reducing time perception sensitivity.

Similar to classic joint action task paradigms (e.g., joint Simon task, joint ensemble coding task) (Zheng & Wang, 2024b; Beurenaut et al., 2021), the present study found that even without shared goals, partner task information is represented as prior information and influences time perception task performance in joint contexts. Previous individual-level time perception research indicates that historical prior information primarily influences time perception through central tendency and sequential dependence effects. When extended to joint contexts, the present study first found, consistent with individual-level research (Jazayeri & Shadlen, 2010; van Rijn, 2016), an asymmetry in central tendency bias effects, manifesting only in long-duration conditions and always biasing toward the partner's task interval. According to Bayesian models of time perception (Jazayeri

& Shadlen, 2010; Shi et al., 2013; Sadibolova & Terhune, 2022), the integration of prior temporal information (i.e., internal temporal memory representations formed from previous tasks) and current accumulated sensory temporal information (i.e., newly received information) as a posterior distribution jointly determines time estimation. Compared to individual contexts, prior information received in joint contexts mixes self-task and partner-task information, causing the posterior distribution to bias toward the partner's temporal interval. These results further extend Bayesian time perception models to social contexts. In non-temporal joint tasks, Zheng and Wang (2024b) found similar central tendency bias effects in joint contexts, where ensemble coding results biased toward partner task information. Moreover, that study verified the causal mechanism of co-representation through manipulation of intergroup relationships (Zheng & Wang, 2024b). Similarly, Experiment 3 of the present study verified the co-representation mechanism in joint time perception central tendency bias effects by weakening co-representation strength through the non-target context. On the other hand, consistent with sequential dependence effects at the individual level (Shi et al., 2013), all three experiments found significant sequential dependence effects, with bias effects significantly larger following other trials than self trials. Critically, sequential dependence effects did not differ significantly across the three experimental contexts, indicating that this effect itself is not influenced by contextual changes. Therefore, unlike previous individual-level time perception research, joint context effects on individual time perception are only reflected in central tendency bias effects. Specifically, when storing trial information in long-term memory to form prior information distributions across trials, partner task trials may be segregated from non-partner task trials due to the high social salience conferred by co-representation mechanisms (Tseng et al., 2022; Sui et al., 2013; Zheng & Wang, 2024b), thereby influencing the posterior distribution and ultimately manifesting as central tendency bias effects.

Furthermore, building upon previous individual-level time perception research, the present study investigated whether the factor of "others' presence" would elicit social facilitation effects that compete for limited attentional resources and influence time estimation task performance. Consistent with our hypotheses, time perception sensitivity significantly decreased in partner-present conditions (Experiment 1 joint context and Experiment 3 non-target context) compared to partner-absent conditions (Experiment 1 individual context and Experiment 2 belief context). These results replicate classic social facilitation findings that others' presence competes for limited attentional resources (Mnif et al., 2022; Zang et al., 2022; Oliva et al., 2017), reducing attentional resource allocation to time perception tasks and consequently decreasing time perception sensitivity. In fact, these results parallel time perception task effects in dual-task paradigms. When individuals simultaneously perform temporal and non-temporal tasks, non-temporal tasks compete for attentional resources, leading to significantly decreased time perception sensitivity that correlates closely with non-temporal task difficulty (Brown, 1985). This phenomenon may stem from the additional cognitive resources required during joint action to monitor one's own and others'

actions and related task outcomes (Sebanz et al., 2021). For example, Loehr et al. (2013) recorded EEG activity during piano duet performances and found similar neural responses to self- and other-generated errors in early detection. These results suggest that in joint action contexts, others' presence increases attentional resource allocation to partner tasks through social facilitation effects while simultaneously reducing focus on one's own task, which may be the key mechanism underlying decreased time perception sensitivity. An alternative explanation based on Bayesian time perception theory suggests that integrating partner task temporal information as prior information may cause shifts in subjective equality points and reduce time perception sensitivity by interfering with response criteria. As shown in Experiment 1's psychometric curves (Figure 2), compared to individual contexts, joint contexts not only exhibited significant subjective equality point shifts but also showed particularly pronounced judgment errors and sensitivity decreases when participants' task intervals approached their partner's task intervals. Experiment 3 also observed sensitivity decrease trends, but because the partner's task was unrelated to time, no subjective equality point shifts occurred. Although Bayesian integration theory can explain results from Experiments 1 and 3, it cannot account for Experiment 2's findings, which showed significant subjective equality point shifts without corresponding sensitivity changes. Therefore, we favor the interpretation that others' presence influences time perception sensitivity by competing for attentional resources rather than by altering perceptual performance through integration of partner task information. It is important to emphasize that attentional resource competition typically affects both subjective equality points and sensitivity in dual-task conditions, but participants in the present study completed tasks independently rather than in a typical dual-task situation. Therefore, others' presence primarily affects the current stimulus processing state by diverting attention, reducing time perception sensitivity without significantly altering integration of partner temporal prior information.

In summary, the present study provides empirical evidence for the psychological mechanisms of time perception in social contexts and expands the research contexts for time perception. However, several limitations remain. First, following previous joint action paradigms, the present study used different colors as agent discrimination cues with between-subject counterbalancing. However, given previous findings that stimulus color may influence time perception (Lin, 2003), future research should consider using non-color agent discrimination cues. Second, Experiments 2 and 3 employed confederates as partners to complete joint context tasks. Although this design controlled for partner behavior consistency, it may differ in ecological validity from real joint action in Experiment 1. Future research should employ authentic joint action contexts to minimize these additional factors. Additionally, future studies should combine cutting-edge interpersonal neuroscience measurement methods to further investigate the neural mechanisms corresponding to individual time perception psychological mechanisms in joint action contexts.

The present study systematically investigated the influence of joint action con-

texts on individual time perception through three experiments, revealing the important roles of co-representation and social facilitation. Results demonstrate that individuals' subjective time estimation biases toward their partner's temporal interval in joint contexts, while others' presence consumes attentional resources, thereby reducing time perception sensitivity. This research not only expands theoretical perspectives on time perception but also provides important reference for elucidating time perception processing mechanisms in social contexts.

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