

Representation of Task-Irrelevant Information in Joint Statistical Learning

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Abstract

This study investigates whether individuals in a joint context can overcome the limitations of individual-level statistical learning, and further represent and integrate irrelevant information from their own tasks. By manipulating individuals' attentional patterns toward sequences, the study differentiates between task-relevant and irrelevant stimuli. The results show that individuals in a joint context can process irrelevant stimuli from their own tasks, and also represent irrelevant information from their partner's task. This indicates that the joint context can enhance individual attention, enabling individuals to attend to irrelevant information in the task and learn sequential rules.

Full Text

Preamble

Representation of Task-Irrelevant Information in Social Statistical Learning

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Abstract

This study investigated whether individuals can transcend the limitations of individual-level statistical learning in joint contexts to encode and integrate task-irrelevant information. By manipulating co-actors' attentional patterns toward sequences, we distinguished between task-relevant and irrelevant stimuli. Results demonstrated that co-actors could process irrelevant stimuli within their own tasks while also representing task-irrelevant information from their partner's task. These findings indicate that social contexts broaden attentional scope, enabling individuals to attend to and learn task-irrelevant information during sequence learning.

Keywords: social statistical learning, task-irrelevant information, attention

1. Introduction

Collaborating with others represents a crucial social skill (Sebanz et al., 2006). When coordinating actions with others, individuals tend to represent their partner’s movements or task attributes (Knoblich et al., 2011). Among these social cues, the regularities underlying others’ actions constitute vital information, and individuals can learn their partner’s task sequences through joint practice—a phenomenon termed social statistical learning (Zheng & Wang, 2023).

Research on statistical learning (SL) demonstrates that individuals are sensitive to the statistical regularities embedded in continuous stimulus streams (Brosowsky et al., 2021; 徐贵平等, 2020). However, studies at the individual level reveal that task-irrelevant stimuli are not represented. For instance, when presented with two sets of shape-regular stimuli differing in color, participants only learn the regularities of the attended stimuli and fail to encode statistical information in task-irrelevant stimuli (Turk-Browne et al., 2005). This effect persists across different age groups (Cox & Aimola Davies, 2022). Similar findings emerge in auditory SL tasks, where only speech regularities in the attended channel are reliably identified (Papoutsi et al., 2024). Collectively, these studies suggest that selective attention regulates SL effects: individuals allocate more attention to task-relevant stimuli requiring responses while actively ignoring irrelevant stimuli, resulting in asymmetric attentional distribution that confines learning to attended stimuli.

Recent research, however, indicates that social context constitutes a powerful contextual modulator. When a partner is present, individuals expand their attentional scope and allocate attention to the partner’s task (Sakata et al., 2021; Kourtis et al., 2014), actively monitoring its content (Balasubramaniam et al., 2014). For example, Zang et al. (2022) found that in social contexts, participants could attend to and process contextual cues from both their own and their partner’s tasks. After practicing with a partner, participants learned the associations between contextual cues and targets for each actor; when contextual cues were swapped, participants could utilize their partner’s cues to facilitate their own target search. Zheng and Wang (2023) employed a statistical learning task and found that individuals in social contexts could represent task-irrelevant sequence rules from others. Their study established a joint statistical learning paradigm and demonstrated that after practice, both individuals showed significantly reduced reaction times (RTs) for their own and their partner’s sequences. This suggests that individuals process partner information based on the partner’s intentions (i.e., “functional equivalence”), thereby learning the partner’s sequence rules, supporting the co-representation theory (Knoblich & Sebanz, 2006). Consistent with previous research (Bönstrup et al., 2019), comparing RT differences between the beginning and end of each learning block (online

phase) and between pre- and post-rest periods within each block (offline phase) revealed that learning effects for one's own sequence primarily occurred during the offline phase characterized by rapid memory consolidation. These results partially transcend individual-level SL limitations by demonstrating that individuals can learn task-irrelevant partner sequence information. However, this study did not provide direct evidence for learning irrelevant information within either one's own or the partner's statistical learning task.

Building upon Zheng and Wang's (2023) paradigm, the present study introduced task-irrelevant stimuli to further investigate learning of irrelevant information from both one's own and the partner's tasks in joint contexts. Based on previous research (Zang et al., 2022; Zheng & Wang, 2023; Gobel & Giesbrecht, 2020), we hypothesized that the broadened attentional scope in joint contexts is general, predicting that individuals should learn all information in statistical learning tasks, including irrelevant stimuli. Conversely, the "functional equivalence" account of co-representation suggests that individuals should not represent irrelevant information in the partner's task. According to this view, partner task representation depends on the partner's intentions: like the partner themselves, individuals would only process task-relevant information and fail to represent task-irrelevant stimuli (汪俊等, 2023). At the individual level, both hypotheses support that joint contexts facilitate processing and integration of one's own task-irrelevant information. However, they diverge regarding whether individuals can represent irrelevant information from the partner's task. This study aimed to resolve this discrepancy by examining the representation of irrelevant stimuli in the partner's statistical learning task.

Additionally, Zheng and Wang (2023) demonstrated that learning effects for one's own complete sequence occurred primarily during the offline phase. However, when statistical regularity sequences comprise both relevant and irrelevant stimuli, individuals may need to allocate more cognitive resources to online processing and integration, potentially shifting the corresponding learning effects to the online learning phase.

2. Experiment 1

Using the joint statistical learning paradigm, Experiment 1 manipulated individuals' attentional patterns toward their own sequences to examine whether participants could learn sequence rules under different attention modes in joint contexts, thereby clarifying the representation of irrelevant stimuli in one's own and the partner's tasks.

2.1.1 Participants

A power analysis using G*Power 3.1 indicated that 36 participants were required to achieve 95% statistical power with an effect size f of 0.25 and α level of 0.05. We recruited 40 female university students (mean age = 21.48 years), all right-handed with normal (or corrected-to-normal) vision and no color blindness or

weakness. Participants were randomly paired. The study was approved by the institutional ethics committee, and participants received compensation after the experiment.

2.1.2 Materials and Procedure

The experiment comprised shape and position tasks. As shown in [Figure 1: see original paper], in the shape task, upright or inverted triangles ($5.72^\circ \times 5.72^\circ$) were presented at the center of the screen following the shape sequence rule T-I-I-T-T-I-T-I (T = upright triangle, I = inverted triangle). In the position task, two white solid squares ($5.72^\circ \times 5.72^\circ$) were presented horizontally and symmetrically on both sides of the screen (8.57° from the central fixation point), and a black square ($0.95^\circ \times 0.95^\circ$) appeared inside one of the white squares following the position sequence rule L-R-L-L-R-R-R-L (L = left, R = right).

The position and shape sequences maintained their relative order while interleaving to generate 28 different mixed sequences (e.g., T-L-I-R-L-I-T-T-L-I-T-R-I-R-R-L). Twenty-four sequences were used in the learning phase, with the remaining four used in pre- and post-test phases. The same mixed sequences were used across participants.

The experimental procedure consisted of pre-test, learning, and post-test phases, with stimuli presented according to the mixed sequence order in each phase. During pre- and post-test phases, both participants judged triangle types in the shape task and black square positions in the position task, making corresponding keypress responses. In the learning phase, participants practiced sequences: one participant responded to all stimuli in the shape sequence (full attention), while the other responded only to randomly selected stimuli in the position sequence (cued by a black frame; partial attention). Learning of one's own practiced sequence constituted direct learning, while learning of the partner's sequence constituted indirect learning. For example, for a participant under partial attention, learning of their own position sequence was direct learning, whereas learning of their partner's shape sequence was indirect learning.

In all three phases, after a 1-s fixation, participants responded to the presented position or shape stimuli (response keys: QWRT and YUOP; Q or Y = upright triangle, W or U = inverted triangle, R or O = left, T or P = right). Stimuli remained for 2 s or until a response was made, with a 1-s inter-trial interval. Attention mode, task type, and response key assignments were counterbalanced across participants.

Pre- and post-test phases each comprised 32 trials. The learning phase included 384 trials (half shape, half position trials) divided into six blocks. To ensure sufficient offline learning, we programmed at least 10 s of rest between blocks. Inter-phase intervals lasted 5 minutes, with total experiment duration of 30–40 minutes. The experiment ran on E-Prime 3.0 with a 1920×1080 pixel display at 60 Hz refresh rate. Participants sat 60 cm from the screen.

2.2 Results

Test Phase: Using reaction time as the dependent variable, we constructed a linear mixed model (LMM) with attention mode (full attention, partial attention), learning type (direct learning, indirect learning), test phase (pre-test, post-test), and their interactions as predictors, incorporating maximal random effects (Barr et al., 2013). Using R software with the lme4 and buildmer packages, we determined the optimal LMM and estimated effect sizes f^2 and BF_{10} using the effectsize package and the algorithm from Aguasvivas et al. (2024).

Results revealed a significant main effect of test phase ($b = 40.97$, $SE = 6.20$, $t = 6.61$, $p < 0.001$, $f^2 = 1.07$, $BF_{10} = 1.42 \times 10^6$), with participants responding faster in the post-test phase ($M = 520.85$, $SE = 6.60$) than in the pre-test phase ($M = 561.83$, $SE = 8.30$). This indicates that both participants learned sequence rules under different attention modes for themselves and their partner, supporting the notion that social contexts broaden attention, enabling learning of irrelevant stimuli in both one's own and the partner's tasks. The two-way interaction between test phase and attention mode was significant ($b = 14.45$, $SE = 6.20$, $t = 2.33$, $p = 0.020$, $f^2 = 0.38$, $BF_{10} = 1.38 \times 10^8$). By calculating RT differences between pre- and post-test, we found that learning effects were greater under full attention ($M = 55.42$, $SE = 7.98$) than under partial attention ($M = 26.53$, $SE = 6.14$) ($b = 14.45$, $SE = 4.88$, $t = 2.96$, $p = 0.008$, $f^2 = 0.68$, $BF_{10} = 59.74$).

[Figure 1: see original paper] Schematic diagram of Experiments 1 and 2

Learning Phase: To verify that direct learning effects stemmed from individual practice, we constructed an LMM with reaction time as the dependent variable and attention mode (full attention, partial attention) and block (1–6) as predictors. Results showed a significant main effect of block ($b = -12.37$, $SE = 1.12$, $t = -11.03$, $p < 0.001$, $f^2 = 0.78$, $BF_{10} = 9.84 \times 10^{19}$), with RTs gradually decreasing across blocks (Spearman $r = -0.26$, $p < 0.001$). Additionally, the main effect of attention mode was significant ($b = -32.46$, $SE = 13.64$, $t = -2.38$, $p = 0.017$, $f^2 = 0.35$, $BF_{10} = 22.44$), with lower average RTs under full attention ($M = 485.32$, $SE = 6.37$) than under partial attention ($M = 543.19$, $SE = 9.39$). These findings confirm direct learning effects for one's own sequence during the learning phase, with better learning under full attention.

We calculated RTs for online and offline phases within each block to examine sequence learning during practice and brief rest periods (Quentin et al., 2021). When participants showed sequence learning effects, online or offline learning effects were significantly greater than chance. One-sample t-tests revealed significant offline learning effects under full attention ($t = 2.11$, $p = 0.048$, Cohen's $d = 0.47$, $BF_{10} = 1.43$) and significant online learning effects under partial attention ($t = 2.13$, $p = 0.046$, Cohen's $d = 0.48$, $BF_{10} = 1.48$). This indicates that direct learning effects under full attention occurred primarily during the offline phase, whereas consistent with our hypothesis, direct learning effects under partial attention occurred mainly during the online learning phase.

[Figure 2: see original paper] Reaction time results for the test phase of Experiment 1. Note: Error bars represent standard errors. *** $p < 0.001$

[Figure 3: see original paper] Results for the learning phase of Experiment 1. Note: Error bars represent standard errors. * $p < 0.05$

3. Experiment 2

Experiment 1 demonstrated that individuals in joint contexts can process and integrate irrelevant information to form sequence rules. Experiment 2 established a single-person baseline during the practice phase to verify the critical role of social context (i.e., partner presence) in producing the effects observed in Experiment 1.

3.1.1 Participants

Power analysis indicated that 52 participants were needed to achieve 95% statistical power. Experiment 2 recruited 52 female university students (mean age = 20.63 years), all right-handed with normal or corrected-to-normal vision and no color blindness or weakness.

3.1.2 Materials and Procedure

Materials and procedures were identical to Experiment 1, with one key difference: during the learning phase, one participant practiced their sequence alone (with-practice condition), and their learning of the practiced sequence constituted direct learning while learning of the unpracticed sequence constituted indirect learning. The other participant rested in a separate room (without-practice condition; baseline). Following Zheng and Wang's (2023) Experiment 2, we defined learning of the partner's unpracticed sequence as direct learning and learning of the partner's practiced sequence as indirect learning for the no-practice individual, examining RT differences between pre- and post-tests for both with-practice and no-practice individuals. Attention mode and task type were counterbalanced across participants.

3.2 Results

Test Phase: We conducted an LMM analysis with attention mode (full attention, partial attention), learning type (direct learning, indirect learning), test phase (pre-test, post-test), practice condition (with practice, without practice), and their interactions as predictors. Results revealed a significant four-way interaction among attention mode, learning type, test phase, and practice condition ($b = 7.12$, $SE = 3.59$, $t = 1.98$, $p = 0.047$, $f^2 = 0.23$, $BF_{10} = 4.17 \times 10^9$). Further analysis showed that under partial attention, no main effects or interactions were significant ($|t|s < 1.00$, $ps > 0.050$), indicating no learning occurred for participants under partial attention. Under full attention, the three-way

interaction among learning type, test phase, and practice condition was significant ($b = 13.86$, $SE = 5.33$, $t = 2.60$, $p = 0.009$, $f^2 = 0.53$, $BF_{10} = 3.94 \times 10^6$). Further analysis revealed that only under the with-practice condition did the two-way interaction between learning type and test phase reach significance ($b = 21.08$, $SE = 7.89$, $t = 2.67$, $p = 0.008$, $f^2 = 0.77$, $BF_{10} = 8701.85$). Specifically, in single-person contexts, participants could not represent stimuli in task-irrelevant sequences ($t = 0.15$, $p = 0.881$) but could represent their own sequence rules under full attention after practice ($t = -2.59$, $p = 0.018$). Additionally, no-practice individuals showed no learning effects under any condition.

[Figure 4: see original paper] Reaction time results for the test phase of Experiment 2. Note: Error bars represent standard errors. * $p < 0.05$

Learning Phase: The main effect of block was significant ($b = -14.63$, $SE = 2.66$, $t = -5.50$, $p < 0.001$, $f^2 = 1.12$, $BF_{10} = 1.79 \times 10^4$), with RTs gradually decreasing (Spearman $r = -0.30$, $p < 0.001$). However, online and offline learning analyses revealed that only participants who practiced under full attention showed offline learning effects ($t = 2.89$, $p = 0.014$, Cohen's $d = 0.80$, $BF_{10} = 4.50$), while participants under partial attention showed no learning. This confirms that in single-person contexts, individuals consolidate sequence information requiring responses during rest periods.

[Figure 5: see original paper] Results for the learning phase of Experiment 2. Note: Error bars represent standard errors. * $p < 0.05$

4. General Discussion

This study created joint and single-person contexts, manipulating individuals' attention to their own sequences in a joint statistical learning task. We found that in joint contexts, individuals can process irrelevant stimuli in their own tasks and also process irrelevant stimuli in their partner's tasks. Results from Experiments 1 and 2 indicate that learning of irrelevant stimuli in statistical learning tasks occurs exclusively in joint contexts, whereas in single-person contexts, individuals can only learn complete sequences that are fully practiced (i.e., under full attention).

Consistent with our hypotheses, individuals in joint contexts can represent irrelevant stimuli in their own tasks. Previous single-person research demonstrates that selective attention regulates SL effects: attention is influenced by task relevance, such that only task-relevant stimuli are processed while irrelevant stimuli are ignored (Papoutsis et al., 2024; Cox & Aimola Davies, 2022). However, our findings reveal that individuals in joint contexts can process irrelevant information in their own tasks, integrating relevant and irrelevant stimuli to represent sequence rules. This confirms that attentional scope broadens in social contexts (Zang et al., 2022). Moreover, the partner's presence serves as a strong social cue that elicits joint attention (Sebanz et al., 2006; Vesper et al., 2017), enhancing the association between irrelevant and response-relevant stimuli in one's own task under partial attention and facilitating statistical rule learning.

This socially induced attentional facilitation extends beyond one's own task: individuals under full attention can also represent irrelevant stimuli in their partner's sequences. This aligns with previous joint action research showing that participants can process task-irrelevant contextual cue information from their partner's task (Zang et al., 2022; Zang et al., 2021; Sakata et al., 2021). Thus, the breadth of attention in joint contexts appears general: individuals' cognitive systems are automatically activated by an actively responding partner, sharing tasks and attending to partner stimuli (Dolk et al., 2014). Our participants' representation of their partner's sequences under both full and partial attention supports co-representation theory. However, previous co-representation research suggests that individuals typically process partner task-relevant information (Schmitz et al., 2017) and emphasizes the role of partner intentions (汪俊等, 2023). Our discovery that individuals can represent and integrate partner task-irrelevant stimuli challenges the "functional equivalence" account of co-representation.

In summary, this study provides empirical support for the notion that joint contexts promote the representation of irrelevant information during statistical learning and reveals the possibility that attention during SL is modulated by social context. However, it remains unclear how attention influences cognitive processes and neural mechanisms across different contexts. Future research should investigate the behavioral mechanisms and neural substrates underlying this phenomenon to clarify the interaction between context and attention.

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