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Is the Onset-Based STEARC Effect Culturally Generalizable? Evidence from a Turkish Sample

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Abstract

Spatial–temporal associations are commonly interpreted as behavioral evidence for a left-to-right Mental Time Line (MTL) in cultures with left-to-right reading habits. One prominent example is the Spatial–Temporal Association of Response Codes (STEARC) effect, whereby earlier events are responded to faster with the left hand and later events with the right. However, findings from Turkish samples indicate that spatial compatibility patterns, particularly in the number domain, can vary considerably across tasks and experimental conditions despite consistent left-to-right reading experience. The present study therefore examined whether onset-based STEARC generalizes to Turkish participants using an auditory onset-timing paradigm. Sixty-one participants judged whether the final click of an isochronous auditory sequence occurred earlier or later than expected, responding bimanually according to an MTL-congruent mapping (early-left/late-right) and an MTL-incongruent mapping (early-right/late-left). No overall STEARC effect was observed. Instead, onset timing, response side, and mapping order interacted: the MTL-congruent-first group showed a reversed pattern, whereas the MTL-incongruent-first group showed a regular pattern. Exploratory analyses indicated that both patterns were largely attributable to phase-related changes in response speed. Bayesian analyses favored the absence of an overall effect in the slope analysis, whereas evidence concerning the onset timing × response side interaction was inconclusive. Overall, the findings provide no clear evidence for a reliable onset-based STEARC effect in the present Turkish sample and suggest that left-to-right reading direction alone may not be sufficient to produce a consistently expressed left-to-right Mental Time Line across task conditions.

Introduction

A central question in cultural cognitive science concerns how abstract concepts are mentally represented and how these representations are shaped by cultural experience. Unlike concrete objects, abstract concepts cannot be perceived directly through dedicated sensory systems and instead depend on cognitive mechanisms that integrate perceptual, motor, and linguistic information into coherent conceptual structures (Barsalou, 2008). Time occupies a distinctive position among them: it is experienced continuously, yet no sensory receptor is dedicated to it. Temporal information must instead be reconstructed from changes occurring within both the environment and the organism (Buhusi & Meck, 2005; Paton & Buonomano, 2018). This reconstruction raises the question of what representational format supports it.

A prominent account proposes that temporal concepts are mentally organized along spatial dimensions. According to the Mental Time Line (MTL), earlier events are represented toward one end of an internal spatial continuum and later events toward the other (Bonato et al., 2012; Boroditsky, 2000; Casasanto & Boroditsky, 2008). Rather than constituting a literal spatial map, the MTL is regarded as a representational format that supports the encoding, maintenance, and manipulation of temporal information. This proposal is broadly consistent with theories suggesting that abstract concepts are grounded in sensorimotor experience (Lakoff & Johnson, 1980) and with A Theory of Magnitude (ATOM),

which assumes partially shared representational mechanisms for processing time, space, and number (Walsh, 2003), both of which view spatial representations as a central component of temporal cognition.

Importantly, however, the spatial organization of time is neither entirely fixed nor universal. Its orientation appears to be calibrated, at least in part, by culturally acquired directional experience, including that provided by writing systems, calendars, timelines, and other representations of temporal order. Cross-cultural evidence indicates that in societies with left-to-right writing systems, earlier, past, and shorter events are typically associated with left space, whereas later, future, and longer events are associated with right space (Ding et al., 2015; Fuhrman et al., 2011; Kong & You, 2012; Lakens et al., 2011; Ulrich & Maienborn, 2010; Vallesi et al., 2008). By contrast, speakers of right-to-left orthographies frequently exhibit reversed or mixed spatial mappings (Fuhrman & Boroditsky, 2010; Ouellet et al., 2010; Tversky et al., 1991). Beyond these cross-cultural differences, even brief manipulations of reading experience can temporarily reshape spatial–temporal mappings within the same individuals. Exposure to mirror-reversed text can reverse or attenuate preferred spatial–temporal associations (Casasanto & Bottini, 2014; Pitt & Casasanto, 2016), whereas equivalent experience with mirror writing produces little or no comparable effect (Crossley & Bylund, 2025). These findings suggest that the MTL is better understood as a culturally and experientially calibrated cognitive system than as a fixed representational architecture.

The MTL is a hypothetical cognitive construct rather than a directly observable structure; consequently, evidence for its existence must be inferred from behavior. The Spatial–Temporal Association of Response Codes (STEARC) paradigm has become the principal experimental approach for this purpose, examining whether temporal judgments systematically interact with the spatial organization of responses. Typically, responses are faster when earlier, past, or shorter events are mapped to the left and later, future, or longer events to the right than when these mappings are reversed. Such compatibility effects are widely interpreted as behavioral evidence for the MTL.

Ishihara et al. (2008) demonstrated the effect using an auditory onset paradigm in which participants judged whether tones occurred earlier or later than an expected temporal reference. Participants responded faster when earlier events were mapped to the left response key and later events to the right than under the reverse mapping, a result later replicated by Mariconda et al. (2022). Spatial–temporal compatibility has been reported across a range of temporal domains, including ordinal sequences (Gevers et al., 2003, 2004), semantic past–future concepts (Alptekin & Şişman Bal, 2026; Santiago et al., 2007; Weger & Pratt, 2008), the duration and order of auditory events (Conson et al., 2008; Vallesi et al., 2008), and the tempo of auditory beat sequences (De Tommaso & Prpic, 2020; Mariconda et al., 2026).

However, despite broad agreement that temporal information can become spatially organized, considerably less consensus exists regarding the mechanisms through which this organization is expressed behaviorally. The dominant account, rooted in embodied cognition and Conceptual Metaphor Theory (Casasanto & Boroditsky, 2008; Lakoff & Johnson, 1980), proposes that temporal cognition automatically recruits culturally acquired spatial representations grounded in sensorimotor experience.

From this perspective, the STEARC effect reflects the behavioral expression of an underlying MTL shaped by accumulated spatial experience, including culturally learned habits such as reading direction. Alternative accounts, however, emphasize the role of task-related cognitive processes, arguing that spatial compatibility effects emerge from the temporary organization of temporal information during task performance rather than from the automatic activation of spatial representations. Within these frameworks, working memory, temporal attention, and response selection are considered key determinants of whether temporal information becomes spatially coded (Scozia et al., 2023a, 2023b; Torralbo et al., 2006; van Dijck & Fias, 2011).

Recent findings indicate that the behavioral expression of STEARC depends not only on an underlying MTL but also on the demands of the task and on the procedures through which temporal judgments are collected. Mariconda et al. (2022), for example, showed that Ishihara et al.'s (2008) auditory onset paradigm reliably produces a STEARC effect only when participants explicitly evaluate temporal information, suggesting that direct temporal processing is a prerequisite for spatial compatibility. Likewise, Scozia et al. (2024) found that semantic past–future classification produced compatibility effects across the entire reaction-time distribution, whereas duration discrimination produced them only among slower responses, implying that these tasks engage partly different cognitive operations. Procedural characteristics are consequential in their own right. Dalmaso et al. (2023) reported that duration classification along the vertical axis produced a top-to-bottom mapping when only two durations were used, but an inverted bottom-to-top mapping when a denser set of durations was introduced, and Mariconda et al. (2026) similarly found that spatial associations for slow musical tempos emerged only once stimulus density was increased. Together, these findings suggest that a culturally calibrated MTL is not by itself sufficient to produce a measurable STEARC effect, raising the possibility that different STEARC paradigms recruit partially distinct cognitive processes rather than serving as interchangeable measures of the same underlying temporal representation.

Against this background, the auditory onset paradigm is the case on which these conditions bear most sharply, and the reason is mechanistic rather than procedural. Semantic classification supplies a position on a conventional past–future axis, and duration discrimination supplies an interval that is longer or shorter than a standard; both therefore present participants with something magnitude-like. Judging onset timing supplies neither. It requires that an expectation first be generated from the rhythmic structure of the preceding sequence, and that the arriving event then be evaluated as a signed deviation from the predicted moment (Nobre & van Ede, 2018). What must be spatially organized is a subsecond prediction error rather than a quantity. This distinction matters for an experientially calibrated account of the MTL, because the cultural artefacts that spatialize time do not spatialize this particular code. Written text, calendars, timelines, and progress bars more directly spatialize temporal order or duration than deviations from an expected moment. Thus, if onset timing is spatially coded, that coding is unlikely to have been acquired directly and may instead generalize from temporal codes that are more explicitly spatialized.

Whether such generalization occurs can be examined against a prediction that distinguishes temporal from numerical spatial mappings. Because reading more directly correlates lateral space with temporal and ordinal progression than with numerical magnitude, the two mappings should be calibrated by partly different experiences, and reading direction should bear more directly on the spatial organization of time than on that of number. Pitt and Casasanto (2016, 2020) established this dissociation directly: the mirror-reading manipulation described above left spatial–numerical associations unchanged even as it altered space–time associations, and a subsequent double dissociation showed that reading direction and counting direction can move the two mappings in opposite directions. On this account, readers of a left-to-right orthography should organize temporal progression from left to right even where their spatial–numerical associations are less consistent. Turkish samples provide some support for this expectation. Testing German, Turkish, and Iranian participants, Bulut et al. (2025b) found that Turkish participants did not differ from German participants in how they arranged the successive stages of an event along a horizontal timeline, although their left-to-right numerical compatibility effect was weaker under parity judgment. A past-left/future-right compatibility effect has likewise been obtained when Turkish participants classified temporal words (Alptekin & Şişman Bal, 2026). A left-to-right temporal mapping therefore appears to be available in this population, even though, as the evidence reviewed above indicates, whether it is expressed in any particular task depends on the demands and procedures of that task.

This prediction has not been tested for onset timing. The auditory onset paradigm has been examined in German-speaking (Ishihara et al., 2008) and Italian-speaking (Mariconda et al., 2022) participants, both from left-to-right reading contexts, so it remains unclear whether onset-based compatibility generalizes across different cultural settings with left-to-right literacy. The cross-cultural evidence that does exist comes from temporal-order, semantic, and duration paradigms (Fuhrman & Boroditsky, 2010; Vallesi et al., 2014), and in light of the paradigm differences described above, it cannot simply be extended to onset timing. Examining the paradigm in Turkish participants therefore addresses two questions at once: whether onset-based compatibility generalizes beyond the two populations in which it has been observed, and whether a temporal mapping that reading experience should calibrate is expressed when the temporal dimension must be constructed from an auditory sequence rather than read from a visible spatial layout. This second question is sharply posed by the paradigm, because the lateral dimension is not left implicit. Participants respond under an instructed mapping that assigns earlier and later onsets to left and right keys, so a lateral spatial dimension is available in the response even though none is available in the stimulus. What the task withholds is a visible spatial arrangement of the events themselves and, as noted above, any cultural precedent for spatializing deviations from an expected moment.

To address this question, we examined whether relative auditory onset timing is spatially coded along the horizontal axis in Turkish participants, using a close adaptation of Experiment 1 reported by Ishihara et al. (2008). Participants judged whether the final click of an isochronous auditory sequence occurred earlier or later than expected while completing both MTL-congruent (early-left/late-right) and MTL-incongruent (early-right/late-left) response mappings, with mapping order counterbalanced across

participants. Because the task requires explicit temporal judgments, it satisfies the conditions under which STEARC effects have been reliably observed (Kühne et al., 2025; Mariconda et al., 2022; Scozia et al., 2023b), so a null result could not readily be attributed to insufficient temporal processing.

Based on the MTL framework, the evidence that reading direction calibrates temporal representations more directly than numerical ones, the previous demonstration of left-to-right temporal coding in Turkish participants for past- and future-related words (Alptekin & Şişman Bal, 2026), and the explicit temporal demands of the auditory onset paradigm, we predicted that Turkish participants would exhibit a regular STEARC effect. Specifically, earlier auditory onsets were expected to facilitate left-hand responses and later auditory onsets to facilitate right-hand responses, producing the characteristic onset timing × response side interaction.

A failure to observe a reliable effect would also be theoretically informative. As noted above, onset timing has no obvious spatial analogue in everyday experience. Such a result would therefore suggest that the spatial coding of onset timing is not an automatic consequence of possessing a culturally calibrated MTL, but instead depends on operations that do not necessarily generalize from the temporal codes that cultural artefacts do spatialize.

Method

Participants

An a priori power analysis was conducted using G*Power 3.1 (Faul et al., 2007). Because no effect-size estimate was available for the auditory onset timing task in a Turkish sample, we assumed a conservative effect size. With Cohen's f = .15, α = .05, and 1-β = .80, the analysis indicated that 62 participants were required to detect the onset timing x response side interaction in a 2 x 2 repeated-measures ANOVA.

Eighty-one Turkish-speaking volunteers from Izmir University of Economics took part in the study between May and December 2025. None of the participants reported hearing difficulties or a diagnosed hearing impairment, and all provided written informed consent. Data from 19 participants were excluded because their overall accuracy was below 75%, and one participant was also excluded because of an extreme mean RT value (z = 3.17). After these exclusions, 61 participants, including 40 women and 21 men, aged 18 to 31 years (M = 21.56, SD = 3.31), remained for the statistical analyses. Based on the Edinburgh Handedness Inventory (Oldfield, 1971), 49 participants were classified as right-handed, five as left-handed, and seven as ambidextrous. All participants were native Turkish speakers and therefore had formal literacy experience in Turkish, which is written from left to right. Only six participants reported prior experience with a right-to-left writing system, including Persian, Arabic, or Ottoman Turkish.

Stimuli and Apparatus

Auditory stimuli consisted of 1000-Hz clicks, each 20 ms in duration, delivered binaurally through Robotel SC2500 HS2 headphones. On experimental trials, eight clicks were presented. The sound amplitude was kept constant for all participants at a comfortable listening level. The first seven clicks occurred at a constant inter-onset interval (IOI) of 500 ms, whereas the eighth click occurred either 215 ms earlier or 215 ms later than the expected onset. Accordingly, the interval between the seventh and eighth clicks was 285 ms on early-onset trials and 715 ms on late-onset trials. On catch (no-go) trials, the eighth click was omitted. Stimulus presentation and response recording were controlled using SuperLab 6.4.3 (Cedrus, Inc.) on an HP ProOne 440 All-in-One computer. Responses were collected using the leftmost and rightmost keys (17 cm center-to-center distance) of a horizontally positioned Cedrus RB-730 response pad; active response keys were marked with white stickers.

Procedure

The experiment was conducted individually in a quiet, sound-attenuated room. Participants wore an eye mask throughout the task to eliminate visual input and rested their left and right index fingers on the corresponding response keys. On experimental trials, they listened to the entire click sequence and judged whether the final click occurred earlier or later than expected, responding as quickly and accurately as possible. Reaction time (RT) was measured from the onset of the eighth click, and participants had up to 2000 ms to respond. No response was required on catch trials.

Before beginning each response-mapping condition, participants completed a 15-trial practice block using the corresponding response rule. They completed 200 experimental trials divided into four blocks of 50 trials. Two blocks used the MTL-congruent mapping, in which early-onset trials were assigned to the left key and late-onset trials to the right key, and two blocks used the MTL-incongruent mapping, in which this assignment was reversed. Each block contained 20 early-onset trials, 20 late-onset trials, and 10 catch trials, presented in random order. The order of the two response-mapping conditions was counterbalanced across participants: half completed the two MTL-congruent blocks in the first phase, followed by the two MTL-incongruent blocks in the second phase of the experiment, while the other half completed the reverse sequence. Self-paced breaks were provided between blocks.

The intertrial interval (ITI) was 2000-ms initiated right after a response in early- and late-onset trials. On catch trials, the seventh click was followed by a 4000-ms no-response period, and any response during this interval triggered an auditory warning. At the end of each block, a prerecorded auditory instruction informed participants that the block was complete and that they could remove their eye masks and take a break. Once ready, they read the on-screen written instructions announcing the next response-mapping condition and pressed a key to continue. The experimental session lasted approximately 25–30 min.

Data Preparation and Analysis

Practice and catch trials were excluded from the RT analyses. Of the 160 response-required experimental trials, incorrect responses accounted for 4.67% and were removed. Correct trials with anticipatory responses (RTs < 120 ms; 0.75%) were then excluded, followed by trials with RTs more than 3 SDs above or below each participant's mean RT (1.90%). After all trial-level exclusions, 92.68% of the response-required trials remained for analysis.

Before the main analyses, several procedural checks were conducted. Catch-trial accuracy was examined to assess whether participants attended to the complete auditory sequences, and overall accuracy of experimental (early- and late-onset) trials was calculated as an index of task performance. In addition, the association between participants' mean accuracy and mean RT was examined to assess whether faster responding was accompanied by lower accuracy.

Our primary analysis plan was to test the STEARC effect using the onset timing (early vs. late) × response side (left vs. right) interaction in a 2 x 2 repeated-measures ANOVA. Because response mapping was counterbalanced across participants, we also conducted an exploratory control analysis examining whether the predicted compatibility effect varied as a function of mapping order. To this end, mapping order (MTL-congruent first vs. MTL-incongruent first) was included as a between-subjects factor, resulting in a 2 x 2 x 2 mixed-design ANOVA.

The strength and direction of the STEARC effect were also examined using participant-level slopes. For each participant, difference scores were calculated separately for the early- and late-onset conditions by subtracting mean left-response RT from mean right-response RT ($dRT = RT_{right} - RT_{left}$). These scores were regressed on onset timing, dummy-coded as 0 for early-onset trials and 1 for late-onset trials. With this coding scheme, the unstandardized regression coefficient represents the change in dRT from the early- to the late-onset condition (Fias, 1996; Pinhas et al., 2012). Negative slopes indicate the regular STEARC pattern, reflecting an early-left/late-right association, whereas positive slopes indicate a reverse STEARC pattern, reflecting an early-right/late-left association. Mean slopes were tested against zero using one-sample *t* tests for the full sample and separately for each mapping-order group. The mean slopes of the two mapping-order groups were also compared using an independent-samples *t* test.

All tests were two-tailed, with the alpha level set at .05. All follow-up analyses were Bonferroni-corrected. Alongside the frequentist analyses, corresponding Bayes factors were calculated to distinguish evidence supporting the absence of an effect from merely inconclusive evidence. For the ANOVAs, inclusion Bayes factors (BF_{incl}) were calculated in JASP across matched models. These Bayes factors compare models containing a given effect with matched models that exclude the effect while retaining the same higher-order terms. For the *t* tests, BF_{10} values were calculated using the default Cauchy prior on the standardized effect size with a scale parameter of $r = .707$. Bayes factors were interpreted following Dienes' (2021) guidelines. For BF_{10}, values greater than 3 and 10 were taken as moderate and strong evidence for the alternative hypothesis, respectively, whereas values below 1/3 and 1/10 were taken as moderate and strong evidence for the null hypothesis, respectively. The same thresholds were applied to BF_{incl}, with values above 3 and 10 indicating moderate and strong evidence for including the effect, and

values below 1/3 and 1/10 indicating moderate and strong evidence for excluding it. Values between 1/3 and 3 were considered inconclusive.

Results

Catch-trial accuracy was high (*M* = 92.75%, *SD* = 16.56), indicating that participants remained attentive to the auditory click sequences throughout the experiment. Accuracy was also high across experimental trials (*M* = 95.33%, *SD* = 4.46). Moreover, overall accuracy did not differ between participants who completed the MTL-congruent mapping first (*M* = 95.34%, *SD* = 4.29) and those who completed the MTL-incongruent mapping first (*M* = 95.31%, *SD* = 4.70), $t(59) = 0.03$, $p = .979$. Together, these findings indicate adequate task engagement and comparable performance across the two mapping-order groups.

The correlation between participants' mean RTs and overall accuracy was not statistically significant, $r = -.15$, $p = .236$, indicating no evidence of a speed–accuracy trade-off.

Descriptive statistics for RTs and accuracy rates across all conditions are reported in Supplementary Online Material (SOM), Table S1.

The 2 x 2 x 2 mixed-design ANOVA revealed a significant mapping order x onset timing x response side interaction, $F(1, 59) = 21.98$, $p < .001$, $\eta_p^2 = .27$, $BF_{incl} = 1.03 \times 10^7$. This result indicates that the STEARC effect varied depending on which response mapping participants encountered first, with the Bayes factor providing strong evidence for including the three-way interaction in the model. Given this significant interaction, this model was interpreted in place of the originally planned 2 x 2 design, which did not yield a significant onset timing x response side interaction when mapping order was disregarded (Fig. 1A, see also SOM Table 2 for the full model results).

As a follow-up for the significant three-way interaction, separate 2 x 2 repeated-measures ANOVAs were conducted for each mapping-order group. In the MTL-congruent first group (*N* = 32), there was a main effect of onset timing. Responses were faster on late-onset (*M* = 485.07, *SE* = 25.47) than early-onset trials (*M* = 538.26, *SE* = 23.47), $F(1, 31) = 19.26$, $p < .001$, $\eta_p^2 = .38$, $BF_{incl} = 22.08$. The main effect of the response side was not significant, $F(1, 31) = 0.002$, $p = .967$, $\eta_p^2 < .001$, $BF_{incl} = 0.22$. Importantly, the onset timing x response side interaction was significant, $F(1, 31) = 22.99$, $p < .001$, $\eta_p^2 = .43$, $BF_{incl} = 8.74 \times 10^5$, providing strong evidence for including the interaction effect in the model. Simple-effects analysis showed that participants responded faster with the right hand on early-onset trials (*MD* = -70.21, *SE* = 18.38, $p = .001$, $BF_{10} = 51.11$) but faster with the left hand on late-onset trials (*MD* = 70.97, *SE* = 16.13, $p < .001$, $BF_{10} = 219.04$), a pattern consistent with a reverse STEARC effect (Fig. 1B).

In the MTL-incongruent first group (*N* = 29), there was no main effect of onset timing, $F(1, 28) = 0.18$, $p = .673$, $\eta_p^2 = .01$, $BF_{incl} = 0.26$. The main effect of response side was significant, $F(1, 28) = 14.79$, $p = .001$, $\eta_p^2 = .35$, with faster right-hand responses (*M* = 515.42, *SE* = 26.62) than left-hand responses (*M* = 549.94,

SE = 24.73). However, the corresponding Bayes factor was inconclusive, BF_{incl} = 1.23. The onset timing x response side interaction was significant, $F(1, 28) = 4.75$, $p = .038$, $\eta_p^2 = .15$, $BF_{incl} = 9.76$, with the Bayes factor providing moderate evidence for including the interaction in the model (Fig. 1C). Simple-effects analysis revealed that right-hand responses were faster than left-hand responses on late-onset trials (*MD* = -76.70, *SE* = 21.90, $p = .002$, $BF_{10} = 22.54$), whereas response side did not differ on early-onset trials (*MD* = 7.64, *SE* = 20.76, $p = .716$, $BF_{10} = 0.21$).

The 2 x 2 x 2 mixed-design ANOVA also revealed significant main effects of onset timing, $F(1, 59) = 8.83$, $p = .004$, $\eta_p^2 = .13$, $BF_{incl} = 4.05$, and response side, $F(1, 59) = 7.12$, $p = .010$, $\eta_p^2 = .11$, $BF_{incl} = 0.41$. Responses were faster for late than early onsets and faster with the right than the left hand. The Bayes factor provided moderate evidence for the onset-timing effect but was inconclusive for the response-side effect. Crucially, the onset timing x response side interaction was not statistically significant, $F(1, 59) = 1.40$, $p = .242$, $\eta_p^2 = .02$, $BF_{incl} = 0.64$, providing no evidence of an overall STEARC effect. The Bayes factor was inconclusive, indicating that the data did not clearly favor either inclusion or exclusion of the interaction. Mapping order interacted significantly with onset timing, $F(1, 59) = 5.17$, $p = .027$, $\eta_p^2 = .08$, $BF_{incl} = 1.51$, and with response side, $F(1, 59) = 7.43$, $p = .008$, $\eta_p^2 = .11$, $BF_{incl} = 0.88$. However, the Bayes factors for both two-way interactions were inconclusive (see SOM Table S3 for the full model results).

Because each response mapping was tied to a different phase of the experiment, the mapping-order-specific STEARC patterns could have arisen from general practice-related speeding rather than from spatial–temporal compatibility itself. In the MTL-congruent-first group, the second phase used the incongruent mapping; thus, faster responses in the second phase would selectively facilitate right-hand responses to early-onset trials and left-hand responses to late-onset trials, producing an apparent reverse STEARC pattern. Conversely, in the MTL-incongruent-first group, the second phase used the congruent mapping, so comparable speeding would facilitate left-hand responses to early-onset trials and right-hand responses to late-onset trials, mimicking the expected regular STEARC pattern. To examine this possibility, we conducted an exploratory phase analysis. RTs were submitted to a 2 x 2 x 2 mixed-design ANOVA with phase (first vs. second) and onset timing (early vs. late) as within-subjects factors and mapping order (MTL-congruent first vs. MTL-incongruent first) as a between-subjects factor.

There was a significant main effect of phase, $F(1, 59) = 21.98$, $p < .001$, $\eta_p^2 = .27$, $BF_{incl} = 1399.44$, indicating that responses were slower in the first phase (*M* = 550.52, *SE* = 18.86) than in the second phase (*M* = 494.14, *SE* = 17.80). There was also a significant main effect of onset timing, $F(1, 59) = 8.93$, $p = .004$, $\eta_p^2 = .13$, $BF_{incl} = 9.91$, with faster responses to late-onset than early-onset trials. The main effect of mapping order was not significant, $F(1, 59) = .36$, $p = .552$, $\eta_p^2 = .01$, $BF_{incl} = 0.39$. The phase x mapping order interaction was not significant as well, $F(1, 59) = 1.40$, $p = .242$, $\eta_p^2 = .02$, $BF_{incl} = 0.51$, indicating that the difference in RTs between the first and second phase did not differ significantly between the two mapping-order groups. The onset x mapping order interaction was significant, $F(1, 59) = 4.64$, $p = .035$, $\eta_p^2 = .07$, $BF_{incl} = 1.95$, indicating that the effect of onset timing differed across the two

mapping-order groups. However, the corresponding Bayes factor was inconclusive. The phase x onset timing interaction was also significant, $F(1, 59) = 6.53$, $p = .013$, $\eta_p^2 = .10$, $BF_{incl} = 2.14$, indicating that the degree of speeding from the first to the second phase varied between early- and late-onset trials. The Bayes factor for this interaction was likewise inconclusive.

Most importantly, the three-way phase × onset × mapping order interaction was significant, $F(1, 59) = 6.81$, $p = .011$, $\eta_p^2 = .10$, $BF_{incl} = 5.37$. Pairwise comparisons examined the phase difference (Phase 1 vs. Phase 2) separately for each combination of mapping order and onset timing (Fig. 2). In the MTL-congruent-first group, RTs in the second (MTL-incongruent) phase were faster than in the first phase for both early-onset ($MD = 70.92$, $SE = 18.36$, $p < .001$, $BF_{10} = 56.69$) and late-onset trials ($MD = 70.21$, $SE = 16.16$, $p < .001$, $BF_{10} = 189.89$), indicating a comparable speed-up across both onset conditions. In the MTL-incongruent-first group, the second (MTL-congruent) phase showed a smaller speed-up for early-onset trials ($MD = 9.12$, $SE = 20.21$, $p = .652$, $BF_{10} = 0.22$) than for late-onset trials ($MD = 75.18$, $SE = 21.80$, $p < .001$, $BF_{10} = 20.61$).

Together, the primary and phase-based analyses provided no evidence of an overall STEARC effect. In the MTL-congruent-first group, the reverse STEARC pattern could be explained by a comparable speeding from the first to the second phase for both onset conditions, the magnitude of which closely corresponded to the reversed compatibility effect observed in the main analysis. In the MTL-incongruent-first group, the expected STEARC pattern appeared to be driven primarily by selective second-phase speeding for late-onset trials. Overall, these findings suggest that the onset timing x response side interactions observed within the two mapping-order groups largely reflected phase-related improvements in performance rather than genuine STEARC effects that differed in direction as a function of mapping order.

The overall mean slope value was positive ($M = 33.97$, $SD = 217.97$) and did not differ significantly from zero, $t(60) = 1.22$, $p = .228$, Cohen's $dz = .16$, $BF_{10} = 0.28$, indicating no overall STEARC effect at the group level. Importantly, the Bayes factor provided moderate evidence for the null hypothesis.

In the MTL-congruent-first group, slopes were positive ($M = 141.18$, $SD = 166.56$) and differed significantly from zero, $t(31) = 4.80$, $p < .001$, Cohen's $dz = .85$, $BF_{10} = 607.71$, indicating a reverse STEARC effect. In the MTL-incongruent-first group, slopes were negative ($M = -84.34$, $SD = 208.48$) and significantly differed from zero, $t(28) = -2.18$, $p = .038$, Cohen's $dz = .40$, $BF_{10} = 1.51$, indicating a regular STEARC pattern (see SOM Figure S1 for the corresponding dRT patterns for both groups). An independent-samples t test showed that mean slopes differed significantly between the two mapping-order groups, $t(59) = 4.69$, $p < .001$, Cohen's $d = 1.20$, $BF_{10} = 1067.92$. The participant-level slope results therefore provided a complementary representation of the mapping-order-related difference in the direction of the STEARC effect (Fig. 3).

Discussion

Using the auditory onset-timing paradigm, the present study investigated whether a STEARC effect would be observed in a Turkish sample. Overall, participants did not show a reliable early-left/late-right response advantage at the group level. The Bayesian findings provided evidence for the absence of an effect in the slope analysis, whereas the evidence regarding the onset timing x response side interaction remained inconclusive. Taken together, these findings provide no clear evidence that subsecond auditory onset timing was systematically associated with response side in this Turkish sample under the current task conditions.

Although the overall STEARC effect was absent, the interaction between onset timing, response side, and mapping order indicated that the observed response pattern differed according to which mapping was completed first. The congruent-first group appeared to show a reverse STEARC pattern, whereas the incongruent-first group showed a regular pattern. However, because mapping order was necessarily confounded with the experimental phase, these patterns cannot be clearly distinguished from changes in response speed across the experiment. In the congruent-first group, responses became substantially faster in the second phase for both early and late onsets, suggesting a general practice-related improvement rather than a selective spatial–temporal association. In the incongruent-first group, second-phase speeding was pronounced for late onsets but minimal for early onsets, producing a pattern that resembled the regular STEARC effect. Thus, the apparent compatibility patterns in both groups are better understood as consequences of practice and differential adaptation across phases than as evidence for MTLs oriented in opposite directions. Given the absence of an overall compatibility effect, any underlying spatial–temporal response tendency may have been too weak to remain detectable against these broader changes in response speed.

The organization of the response mappings may have contributed to the mapping-order-dependent patterns observed in the present study. Studies using the same auditory onset-timing paradigm alternated congruent and incongruent mappings across four blocks (Ishihara et al., 2008; Mariconda et al., 2022), whereas the present study administered the two blocks with the same mapping consecutively. Consequently, response mapping was confounded with the experimental phase, allowing practice-related changes to contribute to the apparent compatibility patterns within each mapping-order group. However, this design feature is unlikely to fully account for the absence of an overall STEARC effect. Consecutive, counterbalanced mapping phases have produced reliable STEARC effects in several previous studies (Scozia et al., 2024; Vallesi et al., 2008, 2014) and are also commonly used to examine space–number compatibility effects (e.g., Dehaene et al., 1993). Thus, although the grouped block structure limits the interpretation of the mapping-order-dependent patterns, there is little reason to assume that it would, by itself, eliminate a spatial–temporal compatibility effect. The present null finding is therefore notable, as the same auditory paradigm produced reliable STEARC effects in both German and Italian samples, two populations with left-to-right reading habits (Ishihara et al., 2008; Mariconda et al., 2022).

Reading direction has been proposed as an important source of spatial–temporal mappings because reading couples spatial progression with temporal and ordinal progression: material encountered earlier

appears toward the beginning of the scanning path, whereas later material appears farther along it (Ouellet et al., 2010; Pitt & Casasanto, 2016, 2020). Cross-cultural findings support this account but also indicate that the influence of reading direction is not uniform across tasks or populations. In temporal-order judgments, for example, English speakers associated earlier events with the left and later events with the right, whereas Hebrew speakers showed the opposite mapping, even when the stimuli were nonlinguistic (Fuhrman & Boroditsky, 2010). By contrast, Vallesi et al. (2014) observed a regular short-left/long-right STEARC effect in Italian participants but no reliable effect in Israeli participants. They attributed the null finding in the Israeli group to competing directional experiences, as Hebrew text is read from right to left, whereas numbers and additional languages such as English are processed from left to right. Thus, habitual reading direction can shape spatial–temporal mappings, but its behavioral expression may depend both on individuals' directional experiences and on how directly a task connects temporal progression with visually organized space.

This task dependence is important when interpreting the present findings alongside other evidence from Turkish participants. Alptekin and Şişman Bal (2026) found a significant past-left/future-right compatibility effect when Turkish participants classified visually presented temporal words. However, their operationalization differed from the present task in three important respects. First, they examined semantic past–future concepts rather than perceptual early–late onset timing. Second, the stimuli were presented visually rather than auditorily. Third, participants responded using the left and right arrow keys with two fingers of the same right hand rather than making bimanual responses. Some of these differences may be particularly relevant to the influence of reading direction. Visually presented temporal words may more readily activate directional habits associated with reading. In contrast, judgments about the onset timing of auditory events provide no visible spatial arrangement to which habitual reading direction can be directly applied. Effects described as STEARC may therefore reflect partly distinct spatial–temporal correspondences depending on the type of temporal information, stimulus modality, and response requirements (Bonato et al., 2012). Accordingly, the past-left/future-right mapping observed with visually presented semantic concepts may not necessarily generalize to perceptual judgments that depend on establishing a rhythmic temporal expectation and detecting whether an auditory event occurs earlier or later than the expected beat.

Evidence from a horizontal timeline task further supports the possibility that reading direction is more strongly expressed in some task contexts than in others. When Turkish participants were asked to arrange pictures depicting successive stages of an event—an orange being peeled—they predominantly ordered them from left to right, similarly to German participants (Bulut et al., 2025b). In this task, temporal succession was visually explicit and had to be translated into a spatial arrangement, potentially making habitual reading direction especially relevant. Together with the semantic STEARC effect reported by Alptekin and Şişman Bal (2026), this finding indicates that left-to-right spatial–temporal mappings can be elicited in Turkish participants when the stimuli or task provide a direct connection between temporal order and visually organized space. By contrast, the present paradigm required participants to discriminate subsecond differences in the timing of auditory events without a visible spatial sequence. Thus, although reading direction can influence auditory onset-based mappings, as

demonstrated in other left-to-right reading populations, its influence may not have been sufficiently strong to produce a detectable effect in the present Turkish sample under the current task conditions.

The task-dependent pattern observed for spatial–temporal associations is consistent with the heterogeneous space–number compatibility effects previously reported in Turkish samples. Across different tasks and experimental contexts, Turkish participants have shown regular (e.g., Bulut et al., 2025a; Çetinkaya et al., 2026), reversed (e.g., Bulut et al., 2026), and null compatibility effects (e.g., Bulut et al., 2023; Dural et al., 2025). One possible context for this variability is the historical change in the direction of Turkish writing. For approximately six centuries, Ottoman Turkish was written in the right-to-left Arabic–Persian script, before the adoption of the left-to-right Latin alphabet in 1928 (Yılmaz, 2011). Contemporary Turkish readers are educated consistently in a left-to-right writing system and do not generally have direct experience with the earlier script. Nevertheless, formal changes in orthography may not immediately or completely replace the broader directional conventions established within a culture. Turkey's writing history may therefore have contributed to a cultural environment in which directional representations are less uniformly aligned than would be inferred from contemporary reading direction alone. This possibility does not predict a consistently reversed mapping; rather, it may help explain why regular, reversed, and null spatial compatibility patterns emerge across different representational domains and task contexts. From this perspective, the absence of an overall early-left/late-right effect may reflect not a general absence of spatial–temporal coding, but weaker or less consistently activated directional mappings in the present Turkish sample. This historical interpretation remains tentative, however, because the present study did not directly assess participants' culturally acquired directional experiences.

More broadly, the coexistence of competing spatial representations is unlikely to be unique to Turkish culture. Even in populations with relatively consistent left-to-right reading habits, different spatial mappings may become accessible under different task conditions. For example, spatial–numerical compatibility patterns can be reversed when a clock-face representation—in which smaller numbers appear on the right and larger numbers on the left—is made salient, indicating that task context can selectively activate a mapping that conflicts with the conventional left-to-right mental number line (Bächtold et al., 1998; Mingolo et al., 2024). In cultural contexts characterized by multiple or historically changing directional conventions, such as Turkish or Israeli contexts, the range of potentially available mappings may be even more diverse and their activation less consistent across situations. Consequently, spatial compatibility effects may display greater variation across tasks and conditions than would be predicted from contemporary reading direction alone. Cross-cultural research is therefore important not simply for determining whether a particular compatibility effect replicates in another population, but for identifying the conditions under which different culturally available representations guide behavior. Such variation can reveal both the flexibility of spatial representations and the selective influence of cultural experience on their behavioral expression (Pitt and Casasanto, 2020). From this perspective, the present study contributes by showing that a left-to-right auditory onset-based mapping, previously observed in other left-to-right reading populations, was not reliably expressed in a Turkish sample under the current task conditions.

In conclusion, the present study found no overall early-left/late-right compatibility effect in a Turkish sample, despite previous evidence for this effect with the same auditory onset-timing paradigm in other left-to-right reading populations. The mapping-order-dependent patterns appeared to reflect phase-related changes in performance rather than stable spatial–temporal compatibility effects. Considered alongside the diverse spatial compatibility patterns previously reported in Turkish samples, this null finding suggests that contemporary reading direction alone may not consistently predict which spatial mapping will be expressed. More broadly, the findings underscore the importance of studying such effects in diverse cultural contexts and across task conditions to understand how task demands selectively activate culturally available spatial representations.

Declarations

This manuscript is based on İrem Aydın's master's thesis, completed under the supervision of Ezgi Gür at Izmir University of Economics.

Conflict of Interest:

We have no known conflict of interest to disclose.

Ethics Approval:

The study was approved by the Ethics Committee of Izmir University of Economics (approval number: E-97429853-050.04-99242).

Consent to Participate:

All participants provided informed consent prior to participation.

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Author Contribution

All authors contributed to the study conception and design, data analysis, and original draft preparation. Material preparation and data collection were performed by İ.A. All authors read and approved the final manuscript.

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Data Availability

The complete dataset for this study, including raw and filtered data, SPSS data files and outputs, and R script for data preprocessing, is publicly available on the OSF at: https://osf.io/72bkq/overview

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Figures

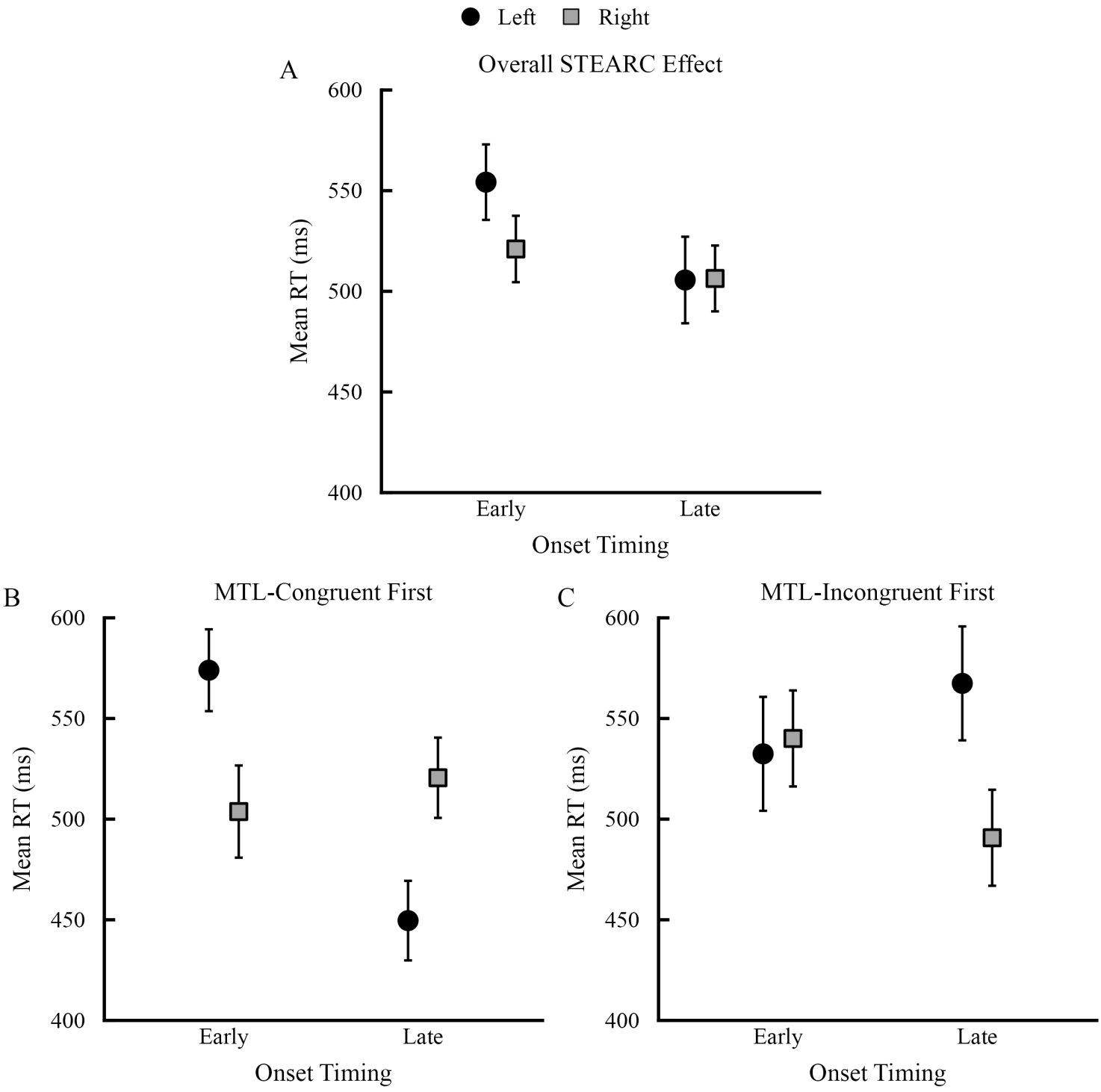


Figure 1

Mean RTs for left- and right-hand responses as a function of onset timing. The upper panel (A) shows the pattern collapsed across mapping-order groups and provides no evidence of an overall STEARC effect. The lower panel shows that the direction of the onset timing x response side interaction differed by mapping order. In the MTL-congruent-first group (B), the pattern was consistent with a reversed STEARC effect, with faster right-hand responses for early onsets and faster left-hand responses for late onsets. In the MTL-incongruent-first group (C), the pattern was consistent with the regular STEARC direction, although the

response-side difference appeared to be driven primarily by faster right-hand responses for late onsets. Error bars represent 95% confidence intervals adjusted for repeated measures.

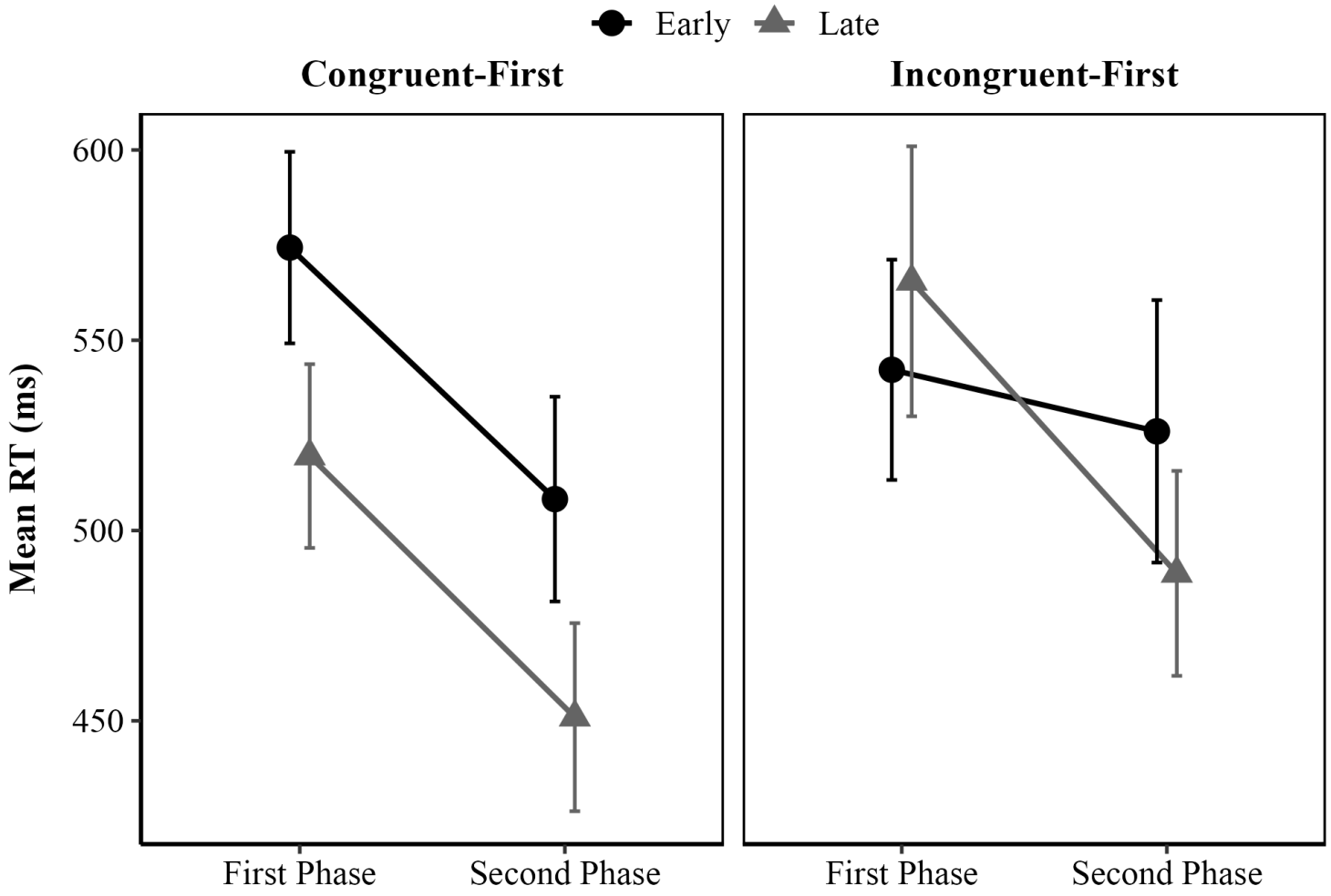


Figure 2

Mean reaction times (RTs) for early- and late-onset trials across the first and second phases, shown separately for the two mapping-order groups. In the MTL-congruent-first group, responses became faster from the first to the second phase for both onset conditions, with a similar degree of speeding for early- and late-onset trials. In the MTL-incongruent-first group, responses to late onsets showed pronounced speeding across phases, whereas responses to early onsets showed minimal change. This asymmetric phase-related speeding may therefore have contributed to the mapping-order-dependent STEARC patterns observed in the main analysis. Error bars represent 95% confidence intervals adjusted for repeated measures.

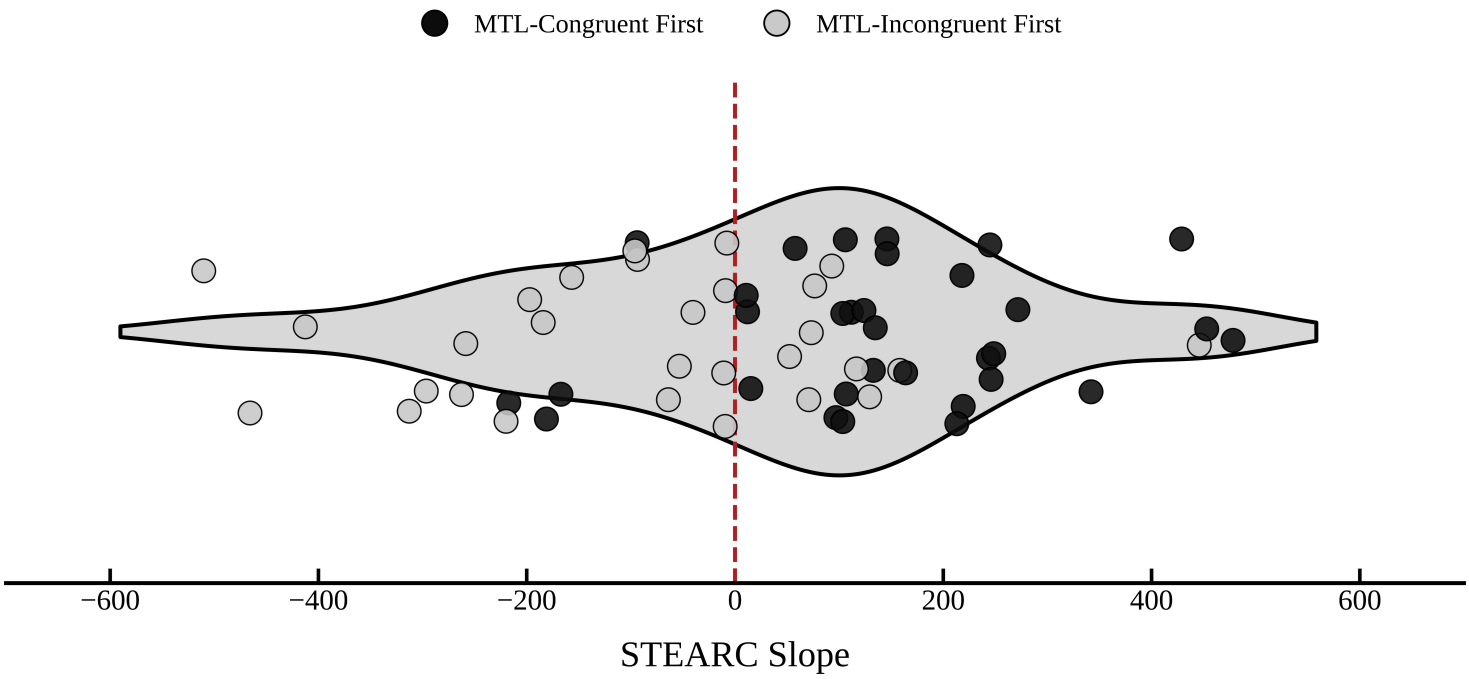


Figure 3

Distribution of participant-level STEARC slopes by mapping-order group. Individual slopes are shown for participants who completed the MTL-congruent blocks first and those who completed the MTL-incongruent blocks first, with the violin plot representing the overall distribution. Negative slopes indicate a STEARC pattern, whereas positive slopes indicate a reversed STEARC pattern. The dashed line marks a slope of zero, corresponding to no association between onset timing and response side.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- STEARCSupplementaryInformation.docx