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Auditory and Verbal Memory in North Indian Tabla Drumming

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Abstract

Tabla denotes a pair of hand drums that is among the most important instruments in North Indian classical music. Tabla is primarily taught through an oral tradition. Compositions are learned via the memorization of sequences of *bols*, solfège-like vocalizations associated with drum strokes. This study probed short-term serial recognition memory of tabla students and musicians who are naïve to tabla. To investigate the role of familiarity and chunking in the cognitive sequencing of tabla, idiomatic tabla sequences of bols and drum strokes were compared with: i) counterparts reversed in order, ii) sequences with random order and identical item content, and iii) items randomly selected without replacement. A strong main effect of sequence type emerged with monotonically decaying performance (i>ii>iii), underlining the role of chunking in auditory serial recognition. Furthermore, differences between tabla players and musicians only emerged for idiomatic sequences of bols, which constitutes a familiarity effect for verbal, but not for instrumental musical timbres. This is interpreted as a partial dissociation of memory for musical and verbal sounds.

Keywords: short-term memory, auditory familiarity, voice superiority, musical timbre, oral musical tradition

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Introduction

A pertinent theme in the study of auditory cognition is the extent to which there is overlap in the cognitive mechanisms involved in the parsing of musical structures and language (see e.g., Patel, 2008; Bigand, Delbé, Poulin-Charronnat, Leman, & Tillmann, 2014; Koelsch, 2009; Williamson, Baddeley, & Hitch, 2010). Short-term memory (STM) is a crucial mechanism for the processing of both music and speech. It is responsible for the storage of sensory and categorical information over time spans of roughly 1–30 s (Jonides et al., 2008; Baddeley, 2012), and thus allows for the integration of strings of words into phrases and sentences, as well as the detection of repetition and variation in musical phrases. Whether STM is a "blank-slate"-type of buffer or affected by the long-term familiarity of stimuli has been intensively discussed in the verbal domain (see e.g., Thorn & Page, 2008; Cowan, 2008; Baddeley, 2012), but research that has directly compared memory for verbal and musical materials has remained scarce.

In the current study, we investigated whether familiarity facilitates auditory short-term serial recognition of sequences comprised of vocal or drum sounds. We explored the example of the *tabla*, a pair of hand drums that is an integral part of North Indian classical music. Its tradition incorporates vocalizations that closely correspond to drum strokes, and thus allows for an ecologically relevant comparison between memory for verbal and instrumental acoustic stimuli. At the same time, tabla music is unknown to many western musicians such that we were able to recruit a truly "naïve" control group of participants, which we compared to a group of tabla students. The example of tabla therefore seems to be well suited to explore the role of long-term experience in the short-term matching of sound sequences, as well as potential differences between memory for speech and musical sequences.

The North Indian tabla

Tabla is among the most versatile instruments in North Indian music. With its great timbral variety, it can be performed solo, in dance accompaniment (*kathak*) or to accompany melodic instruments such as the sitar, violin or voice. There are six primary *gharanas*, that is, stylistic schools that may differ in technique, terminology, and pronunciation (Shepherd, 1976; Gottlieb, 1993). Here we draw from the *Benares gharana*, the tabla lineage that originated in Varanasi. For the sake of consistency, we denote the drums according to the terminology most commonly used by exponents of the Benares gharana, that is, *dahinā* and *bāyāṅ* for the smaller and larger drum, respectively, romanized according to the International Alphabet of Sanskrit Transliteration (IAST). Other common names for the drums include *dayan* or *tabla* for the small drum and *baya* or *bayan* for the larger drum.

Comprising repertoire made up of a multitude of cyclic and cadential compositional forms, tabla has traditionally been taught through a primarily oral tradition (Saxena, 2008). Compositions are usually memorized via a system of *bols* that constitute a solfège system for tabla[1]. Using bols, the sounds of both drums can be expressed either individually or when two sounds are produced at once, simultaneously. As summarized by Shepherd (1976), “The bol is an aid to memory and not a means of notating tabla strokes exactly. Each stroke on the tabla has one or more corresponding bols. The tabla bol does not require the lips to touch and therefore can be spoken at great speed. In fact the recitation of composition is an art practised in itself.”(p. 279)

Tabla vocables have been described as a case of onomatopoeia or verbal sound symbolism (Patel & Iversen, 2003)[2]. It is important to emphasize, however, that the

[1] *Bol* may also be used to refer to whole phrases (such as Ti Ra Ki Ṭa). For the sake of consistency, here we reserve the word to refer to single syllables.

[2] Although this hypothesis is not central to the current study, suffice it to say that its strength compared to the role of associative learning of the bol-stroke correspondence remains subject to debate (cf., McAdams & Patel, 2013; Micallef, 2014).

mapping between bols and tabla sounds may vary across schools, and even more importantly, is not always one-to-one. In the Benares gharana, the relation is dependent on the musical context: Multiple bols may denote the same stroke, but one and the same bol may also refer to different strokes (see Table 1 for examples).

In order to unambiguously characterize our sound stimuli for the purpose of this study, we further use a redundant notation for strokes which combines bols (based on IAST) with sub- and superscript indices that identify the drum and means of sound production. Specifications in superscript refer to the dahinā (usually played by the right hand), subscripts refer to the bāyāṅ (usually left hand): These indicate whether sounds are resonant (o: "open") or damped (x: "closed"). Sounds on the dahinā are further specified by the main point of contact on the drum surface (see Fig. 1), which is either the rim (c: *chāṅṭī*), a circular patch on the drum head (s: *syāhī*), or the remaining head (l: *lao*). Table 1 lists all sounds (including all alternative bols) found in the idiomatic phrases used in the current study. Table 2 provides the combination sounds. For a more comprehensive treatment, we refer to Shepherd (1976).

Insert Fig. 1 around here.

Insert Table 1 around here.

Insert Table 2 around here.

Voice superiority effects

As outlined above, tabla compositions are primarily taught and memorized via the sequencing of verbal material. A natural question regarding this pedagogical practice is whether it exploits processing and memory benefits for conspecific vocalizations. There is a growing number of studies that have not only suggested general processing benefits of vocal compared to instrumental musical timbres (Chartrand & Belin, 2006; Agus, Suied, Thorpe, & Pressnitzer, 2012; Suied, Agus, Thorpe, Mesgarani, & Pressnitzer, 2014), but also enhanced recognition memory of melodies presented via voice timbres (Weiss, Trehub, & Schellenberg, 2012; Weiss, Schellenberg, Trehub, & Dawber, 2015; Weiss, Vanzella, Schellenberg, & Trehub, 2015). The experimental task in the latter studies was to recognize melodies from an exposure phase within a set of foils. Testing adults (Weiss et al., 2012), children from different age groups (Weiss, Schellenberg, et al., 2015), and musicians with and without absolute pitch (Weiss, Vanzella, et al., 2015), results converged on a mnemonic advantage for melodies presented via vocal timbres, even if these were rated as least pleasurable among the test timbres (Weiss et al., 2012). Furthermore, mere timbre familiarity seems an unlikely cause of this effect, given that pianists recognized piano melodies not as well as vocal melodies (Weiss, Vanzella, et al., 2015; see also, Halpern and Müllensiefen, 2008).

Nonetheless, not all studies that address this issue report unambiguous memory advantages for verbal materials. Schulze and Tillmann (2013) compared the matching of sequences of words (presented vocally) with that of sequences comprised of different musical instrument timbres from western orchestral instruments presented with constant pitch. Across three different tasks (forward serial recognition; backward recognition, requiring participants to match a reversed comparison sequence; and backward recognition with articulatory suppression, additionally requiring participants to speak aloud during the retention interval), they compared performance for words to instrumental timbres. Although performance did not differ in absolute terms across the three experiments, backward recognition memory for words was more strongly affected by articulatory suppression than was the case for timbres. Similarly comparing memory across domains, Williamson et al. (2010) suggested that STM for auditorily presented letters and tones from a diatonic scale is shaped by similar mechanisms, such as limited capacity and a detrimental effect of perceptual proximity. In their experiment, notably, only non-musicians' performance was reduced by pitch-proximity, but not that of musicians. This furthermore demonstrates that long-term experience and expertise play a role in STM for musical materials.

Given the emphasis on vocalization in tabla pedagogy, we expected to observe generally better short-term recognition memory for vocal sequences, compared to tabla sequences.

Familiarity and chunking

Familiarity with a musical style may be considered to be both founded on knowledge of a style's basic acoustic units with their characteristic acoustic interrelations and on experience with the ways in which units connect over time to build sequences. Working on the schema of the diatonic scale, Schulze, Dowling, and Tillmann (2012) showed that pitch sequences that conformed to diatonic scales were easier to match to comparison sequences than were non-diatonic sequences for both musicians and non-musicians. The magnitude of the effect varied across different sequence lengths and vanished for backward recognition, which indicates that these effects may be highly sensitive to the specific experimental task. In fact, the sensitivity of familiarity with the experimental task has been a well-known phenomenon for the most prominent familiarity effect in verbal memory, the *lexicality effect*: short-term serial recall of a list of non-words (non-lexical vocables that lack a LTM representation) is worse than that of words, but this difference vanishes for auditory serial recognition (Thorn, Frankish, & Gathercole, 2008; Macken, Taylor, & Jones, 2014). Whereas the contrast of diatonic vs. non-diatonic sequences by Schulze et al. (2012) constitutes a familiarity effect based on a cognitive representation of relations among the test items, namely a scale from which tones are drawn, the results of Vuvan, Podolak, and Schmuckler (2014) highlight effects of knowledge about structures unfolding over time, i.e., sequential schemata. Here the authors showed that tonal melodic expectations affected STM by eliciting more false memories for highly expected tones than for less expected ones. Moreover, the strength with which melodic expectations played into STM was a function of the specificity of the elicited melodic expectations.

Idiomatic tabla phrases are usually constructed by a nested succession of groups of items, or chunks. Cowan (2001) defines a chunk in the psychological sense as a "collection of concepts that have strong associations to one another and much weaker associations to other chunks concurrently in use."(p. 89) It is a classic insight that subdividing memory lists via chunking is a highly effective mnemonic strategy (Miller, 1956). For example, sequences of letters such as IRSCIAFBI are far easier to memorize in terms of the chunks IRS CIA FBI, familiar US federal agencies, than as raw item-by-item successions (Cowan, 2008). Memory over the short term is thus subject to the ways in which LTM mediates chunking of sequences into meaningful subgroups of items.

In the case of tabla, the eight-item phrase comprised by the bols Dhā Dhā Te Ṭe Dhā Dhā Tin Nā, for instance, features the sub-element Te Ṭe, which is a frequently occurring chunk in the tabla repertoire, and so is Dhā Dhā Te Ṭe (see Table 3 for more examples). The latter even constitutes a phrase of a well-known composition often taught to tabla students at a beginner's level (but is also found in numerous other compositions). This means that it not only constitutes a chunk in the sense of being coherent with the tabla style in general, but tabla players may even possess specific LTM representations for this phrase. In this sense,we hypothesized that participants familiar with the tabla repertoire would exploit available LTM representations in order to efficiently encode sequential patterns.

In addition to this latter facet of chunking due to long-term associations between items from the list, there is another facet that is based on the immediate structure of auditory stimuli. In the tabla sequence Dhā Dhā Te Ṭe Dhā Dhā Tin Nā, the subgroups Dhā Dhā and Te Ṭe naturally emerge as chunks, because identical items feature strong associations among each other (Dhā Dhā) and so do very similar sounds with high probability of co-occurrence (Te Ṭe). For that reason, the immediate and non-immediate repetition of items in a sequence not only reduces memory load in terms of item identity, but also facilitates the chunking and segmentation of sequences (Gobet et al., 2001).

Furthermore, idiomatic sequences feature hierarchical structure that arises through nested repetition of chunks, a form of simple temporal recursivity (Jones & Boltz, 1989). The above example can be well subdivided into two phrases, Dhā Dhā Te Ṭe, and Dhā Dhā Tin Na, both of which start with the same chunk and comprise two chunks of two items each. It is likely that this structure is exploited in cognitive sequencing, as listeners have been shown to be sensitive to hierarchical structure both in language and music (Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013; Patel, 2008; Gobet et al., 2001; Bigand, 1990; Jones & Boltz, 1989).

The present experiment

We tested the role of sequential schemata with vocal and percussion sounds from the North Indian tabla in a serial order recognition task. As discussed above, at least three aspects structurally differentiate an idiomatic tabla phrase from a random sequence, and our sequencing factor (within-subjects) attempted to differentiate between these. The factor's first condition comprised idiomatic phrases. The second condition presented the idiomatic sequences in backward order; this operation preserved the hierarchical structure inherent to sequences, but was expected to remove familiarity with the sequential patterns for tabla players, turning familiar idiomatic phrases into non-idiomatic phrases. For "naïve" musicians, we did not expect to observe a difference between these two conditions. The third condition contained sequences with the same items as in conditions 1 and 2 but in a randomly scrambled order. This should remove any effect of hierarchical ordering while preserving the same overall redundancy of items within sequences. As a baseline, items were drawn randomly without replacement from the full set of sounds in the fourth condition. We expected that recognition memory would decay over conditions 2–4 for all participants , but would only be better for condition 1 over condition 2 for tabla players. Regarding the sound material, we expected a main effect of the within-subjects factor of material (table vs. bols) with processing advantages for verbal over drum sounds.

Methods

Participants

Twenty-one tabla players participated in the experiment. They were recruited in a concerted effort among the second author's tabla students. One participant did not have hearing thresholds that fell in the range required for the experiment (see below) and was excluded from the data analysis. For the control group, we tested 23 musicians without experience in tabla. One participant could not complete the experiment due to a fire alarm, the data of two participants were lost due to errors with a computer server.

Tabla players ($N = 20$, 6 female) had a median age of 23 years ($M = 27$, $SD = 11.2$, range: 21–62), had received instruction on a musical instrument for a median of 15 years ($M = 14$, $SD = 4.0$), and a median of 5 years ($M = 5$, $SD = 3.8$) in formal music theoretical training including ear training. At the time of testing, they had played the tabla for a median duration of 11 months ($M = 35$, $SD = 37.7$, range: 3–120) for a median of 5 hours per week ($M = 5$, $SD = 2.3$, range: 3–10). The sample should thus be considered as representing a beginner's level in tabla. Among these, there were eleven participants whose primary instrument was percussion other than tabla, three primary tabla players, three pianists, one guitarist, one flutist, and one saxophonist.

Musicians without experience in tabla ($N = 20$, 9 female) had a median age of 22 years ($M = 23$, $SD = 3.6$, range: 19–36), had received musical instrumental instruction for a median duration of 15 years ($M = 15$, $SD = 4.6$), and possessed a median of 5 years ($M = 6$, $SD = 3.3$) of experience in formal music-theoretical training including ear training. Primary instruments from participants in this group were fairly equally distributed among common western instruments (3 piano, 3 guitar, 3 clarinet, 3 singer, 2 trumpet, 2 cello, 1 violin, 1 viola, 1 acoustic bass, and 1 bassoon).

A standard pure-tone audiogram with octave frequency spacing was measured right before the main experiment (ISO 398-8, 2004 Martin & Champlin, 2000) in order to confirm that participants had hearing thresholds of 20 dB HL or better in the range of

125–8000 Hz.

Stimuli

Individual sounds. Tabla and bol sounds were recorded in a sound recording studio at the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT) in Montreal, QC, Canada, using a matched pair of AKG C414 B-XLS large-diaphragm condenser microphones (AKG Acoustics GmbH, Vienna, Austria) with wide-cardioid characteristics and the Reaper digital audio workstation (Cockos Inc., New York, NY, USA). One microphone was positioned with a vertical elevation of around 20 cm above the drum surfaces, and a direct distance of around 30 cm to both drums. Another microphone was placed around 20 cm in front of the player's mouth for recording the vocalizations. Only the respective mono channel (tabla or bols) was used subsequently. We recorded all common tabla sounds and vocalization as played and spoken in isolation by the second author, a professional tabla player who studied in Varanasi with Pandit Sharda Sahai, a descendant of the founder of the Benares gharana, Pandit Ram Sahai. A realization of every tabla stroke and bol was selected among multiple recordings, followed by manual equalization of the onset lag. In order not to distort natural differences in loudness between stimuli, we normalized the group-averaged root-mean-squared energy (computed for the interval 50–250 ms after stimulus onset of each sound) of all tabla strokes and bols that were used in the experiment. Each sound was then cropped to a duration of 400 ms by applying a 20 ms raised cosine fade-out.

Memory sequences. Every standard sequence consisted of eight sounds. Within sequences, there were 10 ms of silence between sounds, yielding an inter-onset-interval of 410 ms. After the standard sequence, there was a delay of 3280 ms, followed by a comparison sequence that was of identical order in half of the trials and of non-identical order in the other half. In the latter case, items 4 and 5 were swapped. We distributed sounds in the sequencing conditions 2–4 such that items 4 and 5 were fixed across conditions (as outlined below). This held the perceptual dissimilarity of the swap constant across sequencing conditions, because that dissimilarity had been found to be a crucial variable in serial recognition of musical timbre in previous experiments, and had explained a major portion of variance in response choices (Siedenburg & McAdams, in prep.). This seemed to be the only way not to confound the sequencing factor by differing similarities of swaps, while at the same time retaining a feasible design.

There were four sequencing conditions. Condition 1 ("Idio") contained twelve idiomatic tabla sequences that are commonly used in the repertoire of the Benares gharana, the style of the tabla school from Varanasi in North India that the group of tabla participants studied with the second author. They were selected from a larger pool of idiomatic phrases that had been provided by the second author. Selection was based on the criteria that sequences should be isochronous and without gaps (pauses), and that items 4 and 5 should not be identical, but also not very perceptually similar (neither for tabla, nor for bols). Extremely similar items are Te^{xs} and Ṭe^{xs}, or Te^{xp} and Re^{xp}, for instance. Table 3 lists all idiomatic sequences.

Insert Table 3 around here.

As outlined above, the correspondence of bols and strokes is not one-to-one. This resulted in the number of items per sequence being varied across material conditions, although sequences were matched otherwise. We preferred to allow for this variability in order not to render the verbal condition overtly unnatural and irritating to tabla players. This yielded sets of 14 unique tabla stimuli and 16 unique bols from which sequences were constructed. The number of different items per sequence varied between three and six for both material conditions, but with an average number of 4.2 items per sequence for tabla strokes, and 5.1 items for bols.

Condition 2 ("Rev") contained all idiomatic sequences in reversed order. This kept the hierarchical structure of repeating subgroups of items intact, but rendered their sequential structure completely unfamiliar to tabla players. Condition 3 ("RO") presented the same sequences as used in conditions 1 and 2, but shuffled their order, apart from items 4 and 5 which were kept at place for the reasons explained above. This means that for every sequence used in condition 1 (and 2), there existed an analogue in condition 3 that contained the same items in random order. This preserved the same number of items per sequence, but annihilated their hierarchical structure. Condition 4 ("RI") presented randomly drawn items (without replacement) yielding eight different items per sequence. As before, items 4 and 5 from condition 1 were kept in place.

Insert Fig. 2 around here.

In order to measure the effects of random ordering and random item contents on memory, and not the peculiarities of one particular realization of a random process, every participant received different randomizations for conditions 3 and 4.

Presentation and apparatus

The average presentation level was 68 dB SPL (SD = 4.7) as measured with a Brüel & Kjær Type 2205 sound-level meter (maximum level, A-weighting) with a Brüel & Kjær Type 4153 artificial ear to which the headphones were coupled (Brüel & Kjær, Nærum, Denmark). Experiments took place in a double-walled sound-isolation chamber (IAC Acoustics, Bronx, NY). Stimuli were presented on Sennheiser HD280Pro headphones (Sennheiser Electronic GmbH, Wedemark, Germany), using a Macintosh computer with digital-to-analog conversion on a Grace Design m904 (Grace Digital Audio, San Diego, CA) monitor system. The experimental interface and data collection were conducted by the audio software MaxMSP (Cycling 74, San Francisco, CA).

Procedure and design

Participants were presented four example trials, two of which consisted of tabla trials, two of bols. Correct responses were provided on the screen. In the main experiment, they were asked to listen to the two sequences and respond to the question "Was the order of the two sequences identical?" by pressing dedicated "Yes" and "No" buttons on the computer keyboard. After participants had provided their response, the message "recording response" was displayed on the screen for 4 s. They could then proceed to the next trial.

Twelve sequences per condition were presented (each as identical and non-identical standard-comparison pairs), yielding 12×2 (material: tabla vs. bols) $\times$ 4 (sequencing conditions) $\times$ 2 (identical/non-identical) = 192 trials in total. The experiment was administered in a split-plot design, containing four blocks of 48 trials each with material counterbalanced across participants (e.g., tabla-bols-tabla-bols). Sequencing conditions were fully randomized within every block. Every block required around 15 min to complete and participants were required to take breaks of 5 min between blocks. After completing the listening experiment, participants filled out a questionnaire on biographical information, musical background, and strategies employed during the experiment. Participants were compensated with $15 CAD for their time.

Results

Discrimination sensitivity was assessed by calculating d' scores and criterion location c based upon the yes-no model (Macmillan & Creelman, 2005, Ch. 2). Hits were defined as trials that participants correctly identified as non-identical, false alarms as trials that were incorrectly judged as non-identical. No violations of sphericity were observed (Mauchly's test). Figure 3 shows sensitivity and bias for all conditions.

Insert Fig. 3 around here.

A mixed $2 \times 2 \times 4$ ANOVA did not yield main effects of group, $F(1, 38) = 2.32$, $p = .135$, or material, $F(1, 38) < 1$, but a strong main effect of sequencing, $F(3, 114) = 132.1$, $p < .001$, $\eta_p^2 = .776$. The sequencing factor interacted with group, $F(3, 114) = 4.27$, $p = .006, \eta_p^2 = .101$, and material $F(3, 114) = 14.7$, $p < .001$, $\eta_p^2 = .278$. Furthermore, there was a marginally significant three-way interaction between group, material and sequencing, $F(3, 114) = 2.35$, $p = .076$, $\eta_p^2 = .058$.

The main effect of sequencing was qualified by post-hoc contrasts, for which both linear, $\beta = -1.18$, $t(266) = -19.9$, $p < .001$ and quadratic $\beta = -0.25$, $t(266) = -4.3$, $p < .001$ polynomials were significant. Post-hoc comparisons were conducted, here and in the following using the Bonferroni-Holm correction for multiple comparisons with the critical level $\alpha_{crit} = 0.05/k$, k corresponding to the inverse rank order of the corresponding p-value among all p-values considered for the interpretation of the respective (interaction) effect. Comparisons attested that the interaction between sequencing and group occurred because sensitivity was higher for tabla players than for musicians in the idiomatic condition, $t(38) = -3.63, p = .0008$ ($k = 4$, $\alpha_{crit} = .0125$), but the two groups were equivalent in all other three conditions, all $|t(38)| < 0.92, p > .36$. The interaction between sequencing and material factors reflected the greater sensitivity to bols than to tabla strokes in the idiomatic condition, $t(39) = -4.65, p < .0001$ ($k = 4$, $\alpha_{crit} = .0125$), paired with a greater sensitivity for tabla compared to bols in the random order condition, $t(39) = 3.71, p = .0006$ ($k = 3$, $\alpha_{crit} = .0167$). No other significant differences between materials for the remaining two sequencing condition were found, $t(39) < 1.73, p > .09$.

Both two-way interactions, however, appear to be partially driven by the far superior performance of tabla players for idiomatic sequences of bols, giving rise to the (marginally significant) three-way interaction: Tabla players were better than musicians for idiomatic bols, $t(38) = 3.51$, $p = .0012$ ($k = 14$, $\alpha_{crit} = .0036$), but not for idiomatic tabla, $t(38) = 2.08, p = .043$ ($k = 13$, $\alpha_{crit} = .0038$), and there were no other significant differences between tabla players and musicians elsewhere $t(38) < 1.69$, $p > .098$. Furthermore, tabla players were better on idiomatic bols than on idiomatic tabla, $t(19) = -4.46, p = .0003$ ($k = 16$, $\alpha_{crit} = .0031$), but worse for bols compared to tabla on random order sequences, $t(19) = -4.04, p = .0006$ ($k = 15$, $\alpha_{crit} = .0033$). Other differences between tabla and bols for tabla players did not survive correction for multiple comparisons, all $t(19) < 2.38$, N.S.. Similarly, none of the differences between tabla and bol sequences were significant for musicians, all $|t(19)| < 2.27$, N.S..

For tabla players, we did not find significant positive correlations of d' scores and the number of months of experience with tabla in any of the experimental conditions with corrected α-levels, $|r(18)| < .48$, N.S..

Response bias as measured according to the criterion location yielded a main effect of sequencing, $F(3, 114) = 18.3, p < .001, \eta_p^2 = .325$. There was no significant main effect of material, $F(1, 38) = 1.9, p = .174$, nor of group, $F(1, 38) = 1.82, p = .184$. There was no significant interaction, all $p > .10$. Post-hoc t-tests confirmed that the main effect of sequencing on response bias was due to significantly higher bias for the RI condition compared to any other condition, all $t(39) > 4.9, p < .0001$ ($k = 6$, $\alpha_{crit} = .0083$, Bonferroni-Holm corrected α-level), but no differences otherwise, all $p > .57$. This means that in the RI condition, both groups missed more non-identical trials.

In summary, we observed a strong main effect of sequencing condition on sensitivity. As expected, the worst performance occurred for sequences without repeating items (RI), followed by randomly structured sequences with a smaller number of items (RO). Further, sequences that contained hierarchical groupings (Idio and Rev) were memorized most easily. We interpret the interactions between sequencing, material and group to be driven by the superior performance of tabla players on idiomatic bols. Notably, there was no difference between idiomatic and reversed tabla sequences, neither for musicians without experience in tabla (as we expected), nor for tabla players (contrary to our hypothesis). Considering bol vocalizations on the contrary, tabla players were better for idiomatic sequences compared to reversed sequences, but this difference was not statistically significant for musicians without experience in tabla.

Discussion

The current results highlight commonalities and disparities of recognition memory for verbal and musical stimuli. Notably, we only observed facilitated recognition memory for verbal idiomatic sequences, but not for any other sequence types, and differences were only significant for tabla players who had on average 11 months of experience. It should be remarked that both groups of participants were closely matched in terms of their training in Western music, close to a professional level, whereas tabla students were mostly at a beginner's level on the tabla. Within that sample of tabla students, surprisingly, the sensitivity (d' scores) in none of the experimental conditions correlated significantly with the reported number of months of practice on the instrument and the associated vocalizations. These circumstances suggest that the observed facilitation of verbal memory may be due to learning that proceeds comparatively quickly, most likely on the timescale of months. For that reason, we assume that our results may well generalize to groups of tabla players with more experience.

The only notable difference in participants' response bias was between RI sequences and all other sequencing conditions, a circumstance that may reflect the categorical difference in the construction of these sequences. RI was the only sequencing condition that did not contain repetitions of items. Here participants adopted a less "critical" criterion (i.e., more often considering sequences as identical). Sequences in the RO condition contained repetitions of items, thus reducing the memory load in terms of item identity. The Rev and Idio conditions, moreover, contained repeating subgroups of items, therefore potentially allowing participants to hierarchically represent sequences by considering successions of subgroups. Both groups of participants showed a linear decay of sensitivity across these three conditions (Rev > RO > RI), reflecting a mnemonic hierarchy of sequential structure. Although the material factor interacted with that of sequencing, there was no main effect of material, contrary to our hypotheses. Congruent results have been observed for the serial recognition of words and timbres by Schulze and Tillmann (2013). Using three different matching tasks, they did not find differences in performance between sequences of words and timbres. However, they only used non-structured sequences, comparable to the current RI condition.

Limitations of this study

A few potential limitations of the current experimental design deserve further notice. First, it may be recalled that within the group of tabla players, there were only six musicians whose primary instrument was neither tabla nor Western percussion, but in the group of musicians without tabla experience, there were no percussionists. It seems plausible that having percussionists in the group of (non-tabla) musicians may have had some effect on performance in the tabla conditions, but would not be expected a priori to have an effect in the bols conditions. Nonetheless, only the (idiomatic) bols condition yielded significant differences between groups. Therefore, we consider that this aspect did not play a decisive role in the present results.

Second, given that we worked with natural tabla and bol sounds, we did not determine which exact auditory features were decisive for distinguishing items. The most likely candidate attribute is timbre, denoting that bundle of spectrotemporal auditory features that conveys the identity of a sound source and that for many instruments covaries with pitch and loudness (McAdams, 2013). Items within the sets of bols and strokes were not equalized in relative pitch or loudness, however, and it is therefore hard to assess the overall impact of these two attributes. Pitch is an especially salient feature for tabla strokes, because the resonant sounds of the dahinā and bāyāṅ are spaced at around an octave and thus can be easily distinguished. Pitch differences in bols were not as salient, but here participants may have also relied on pitch contour. Notwithstanding, timbre was the only cue that distinguished all items from each other, not only subsets of items, for both sets of bols and strokes.

Finally, in order not to confound the sequencing factor by varying the timbral dissimilarities of the swaps, we kept the positions of the swapped items constant (items 4 and 5). The relevance of this approach was justified by a post-hoc analysis that compared performance on similar and dissimilar swaps of strokes. Similar strokes were here defined, for the lack of direct dissimilarity ratings, as swaps that comprised either both resonant or non-resonant (dampened) strokes, and dissimilar swaps comprised mixed pairs. The hit rate for dissimilar swaps (including 7/12 pairs) was $M = .70$ ($SD = 0.15$), and for similar pairs (5/12 pairs) it was $M = .61$ ($SD = 0.17$). Comparing participant-wise hit rates for these two types of swaps confirmed a highly significant advantage for dissimilar pairs, $t(39) = 4.45, p < .001$. This design may have allowed for the possibility that participants selectively attended to items 4 and 5 without attempting to memorize the full sequence. It seems unlikely that this was the case, however. Participants were asked to describe the strategies they had employed in a questionnaire after completing the experiment. None of the participants mentioned focusing on a particular serial position. To the contrary, musicians reported a variety of different strategies, such as trying to memorize the full sequential pattern, chunking the sequence into smaller subgroups, or focusing on damped-resonant patterns. Tabla players additionally mentioned using idiomatic patterns from the repertoire as a memory aid, associating movements on the instrument with the sequence, or making use of verbal rehearsal. Furthermore, in case a majority of participants would have only focused on these two serial positions, performance would have likely shown ceiling effects across all sequencing conditions, which is clearly not the case. The variety of strategies just mentioned therefore suggests that participants selectively attended to the variety of perceptual-motor affordances of items (cf., Macken et al., 2014), rather than to a limited number of serial positions.

Potential underpinnings

More generally, the current results may be viewed both from encoding and maintenance perspectives. Recall that the idiomatic phrases were composed by subgroups of items that feature a high frequency of co-occurrence and potential LTM representations, and thus are likely to be encoded as chunks by tabla players. Take the phrase Ti Ra Ki Ṭa as an example, a frequently occurring “word” of the tabla repertoire. Instead of memorizing four items, participants who are familiar with the style need only retain one chunk that represents the phrase. Although familiarity-based chunking in immediate memory is usually considered as a domain-general mechanism (Cowan, 2001; Gobet et al., 2001), tabla strokes were curiously not processed in the same way. Otherwise they would have yielded the same boost of recognition performance for idiomatic sequences, and there would not have been an interaction between material, sequencing, and group. Verbal material appears to be particularly suited for chunking, because language learning requires the acquisition of an enormous amount of vocabulary based on the hierarchical representation of chunks of phonological sequences (e.g., Pinker, 1994; Patel, 2008). It thus seems natural that familiar chunks of verbal material are represented most efficiently. Memory for sequences of musical timbres, on the other hand, may be veridical and of high fidelity in immediate recognition, but less apt for hierarchical abstraction via familiarity-based chunking.

Considering subvocal rehearsal as a potential maintenance mechanism, it is clear that all experimental conditions afforded (sub)vocal rehearsal by tabla players in principle (e.g., Baddeley, 2012). In fact, in the course of learning the instrument, students must acquire strong associations of bols and tabla sounds in order to be able to memorize and recite bol sequences. Bols are, of course, particularly suited for subvocal rehearsal because they already are in a verbal format. The current three-way interaction could then be interpreted as caused by facilitated rehearsal of idiomatically structured verbal sequences. In particular, tabla players are trained in the rapid recitation of idiomatic sequences of bols, an ability that may aid subvocal rehearsal. An effect of articulatory fluency on serial recall was observed by Woodward, Macken, and Jones (2008). Their participants were trained to quickly articulate lists of (non-)words, and in consequence showed better recall performance. The advantage was independent of item-wise articulation fluency, but only occurred when lists were composed of items that co-occurred in the training phase. As noted, however, results from serial recall do not directly apply to those from serial recognition, in particular when dealing with familiarity effects (Thorn et al., 2008). Although recognition performance for sequences of timbres and words did not differ in the data of Schulze and Tillmann (2013), backward serial recognition of words with articulatory suppression was significantly worse than without, but not so for timbres. This finding may suggest that articulatory rehearsal processes are preferentially used in verbal memory. Nonetheless, this evidence remains ambiguous for an account solely based on articulatory rehearsal, given that maintenance strategies have been shown to be dependent on the concurrent load in verbal working memory tasks (Camos, Mora, & Oberauer, 2011): in tasks with high concurrent load, subvocal rehearsal was shown to be the predominant strategy of young adults. On the other hand, maintenance strategies such as attentional refreshing were preferentially used in low-load tasks. Due to no interference whatsoever and a relatively short retention interval (3280 ms), the current serial recognition task rather seems to constitute a low-load task, in contrast to backward serial recognition from Schulze and Tillmann (2013) in which participants needed to reverse the order of the standard sequences. For these reasons, the role of subvocal rehearsal in the current results remains questionable. Considering both potential encoding and maintenance processes may nonetheless be the most realistic vantage point for ecologically relevant scenarios, using stimuli that feature a broad array of perceptual-motor affordances.

Conclusion

This study explored the cognitive sequencing of verbal and drum sounds for the example of the North Indian tabla. Regardless of material (verbal bols or drum strokes), we found clear evidence for facilitated recognition memory for well-formed hierarchical patterns compared to randomly ordered sequences. Furthermore, although tabla constitutes a musical tradition that at first glance treats language and music in surprisingly similar ways, human memory appears to feature subtle but important differences in dealing with these two classes of acoustic stimuli. We obtained evidence for a dissociation between memory for verbal and instrumental sounds, that arises in conjunction with familiarity with the musical style. Tabla students better recognized familiar sequences of verbal material compared to sounds of tabla strokes and to a control group of music students without experience in tabla. This dissociation may be one of the driving forces behind traditional tabla pedagogy that requires students to memorize compositions by listening to their teachers' vocalizations, rather than their tabla drumming. Such a claim remains speculative insofar as the role of multimodal cues in short-term memory should not be underestimated (Quak, London, & Talsma, 2015); tabla students' memory may well benefit from *watching* their teachers play. Nonetheless, when memory for auditory stimuli are considered as such, and participants are familiar with the basic building blocks of the repertoire, the results of this study clearly suggest mnemonic advantages for tabla's vocal solfège, underlining the cognitive utility of this centuries-old pedagogical tradition.

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Table 1

Description of strokes and corresponding bols.

Drum	Symbol	Playing technique	Alternative bols
dahinā	Nā^{oc}	Index finger strikes chāṅṭī, while ring finger lightly touches edge of syāhī, producing an overtone	
	Tin^{ol}	Index finger strikes lao, middle finger strikes syāhī, ring finger lightly touches edge of syāhī, producing an overtone	Tā (Tā Ka Tā Ka)
	Tun^{os}	Index finger strikes center of syāhī. NB: in the experiment, this sound is only used in combination (see Table 2), but not solo	
	Ṭe^{xs}	Index finger strikes center of syāhī	Ra (Ti Ra Ki Ṭa), Tā (Ki Ta Tā Ka)
	Te^{xs}	Middle and ring finger strike center of syāhī	Ti, Ṭa (Ti Ra Ki Ṭa)
	Te^{xp}	Right side of palm strikes syāhī and much of lao	
	Re^{xp}	Left side of palm strikes syāhī and much of lao	
bāyāṅ	Ge_{o}	Index or middle finger strikes lao, wrist on head can induce pitch glide	
	Ke_{x}	Flat hand strikes lao and syāhī	Ki, Ka (Ki Ṭa Tā Ka)

Note: In order to uniquely specify tabla strokes, we use a redundant notation that specifies any stroke by its corresponding bol, by whether it is produced on the high-pitched dahinā (superscript indices) or low-pitched bāyāṅ (subscript), and by whether it is resonant (o: "open") or non-resonant (x: "closed"). Any dahinā stroke is further specified by the major point of contact on the drum surface, the rim (c: *chāṅṭī*), the head (l: *lao*), or the black patch in the centre of the drum (s: *syāhī*), or whether the head and rim is struck by the palm (p). The last column lists alternative bols with an examplary context in brackets.

Table 2

Combination sounds of both drums.

Symbol	dahinā	bāyāṅ	Alternative bols
Dhā_o^{oc}	Nā^{oc}	Ge_o	
Dhin_o^{ol}	Tin^{ol}	Ge_o	Dhā (Dhā Ge Te Ṭe)
Dhin_o^{os}	Tun^{os}	Ge_o	
Dhe_o^{xs}	Te^{xs}	Ge_o	
Dhe_o^{xp}	Te^{xp}	Ge_o	
Tin_x^{os}	Tun^{os}	Ke_x	

Note: Notation refers to the second column of Table 1.

Table 3

Idiomatic sequences of tabla strokes (left) and bols (right) as used in the experiment.

Strokes								Bols							
Dhā$_o^{oc}$	Dhā$_o^{oc}$	Te^{xs}	Ṭe^{xs}	Dhā$_o^{oc}$	Dhā$_o^{oc}$	Tin$_x^{os}$	Nā^{oc}	Dhā	Dhā	Te	Ṭe	Dhā	Dhā	Tin	Nā
Ṭe^{xs}	Ke$_x$	Te^{xs}	Ṭe^{xs}	Ke$_x$	Te^{xs}	Ṭe^{xs}	Ke$_x$	Tā	Ka	Ti	Ra	Ki	Ṭa	Tā	Ka
Dhe$_o^{xp}$	Re^{xp}	Te^{xp}	Re^{xp}	Ke$_x$	Te^{xs}	Ṭe^{xs}	Ke$_x$	Dhe	Re	Dhe	Re	Ki	Ṭa	Tā	Ka
Ke$_x$	Te^{xs}	Ke$_x$	Te^{xs}	Ge$_o$	Ge$_o$	Te^{xs}	Ṭe^{xs}	Ka	Ta	Ka	Ta	Ge	Ge	Te	Ṭe
Ge$_o$	Ge$_o$	Te^{xs}	Ṭe^{xs}	Ge$_o$	Ge$_o$	Nā^{oc}	Nā^{oc}	Ge	Ge	Te	Ṭe	Ge	Ge	Nā	Nā
Te^{xs}	Ṭe^{xs}	Ke$_x$	Te^{xs}	Ke$_x$	Te^{xs}	Ṭe^{xs}	Ke$_x$	Ti	Ra	Ki	Ṭa	Ki	Ṭa	Tā	Ka
Te^{xs}	Ṭe^{xs}	Ke$_x$	Te^{xs}	Tin^{ol}	Ke$_x$	Tin^{ol}	Ke$_x$	Ti	Ra	Ki	Ṭa	Tā	Ka	Tā	Ka
Te^{xs}	Ṭe^{xs}	Ke$_x$	Te^{xs}	Tin$_x^{os}$	Nā^{oc}	Tin$_x^{os}$	Nā^{oc}	Ti	Ra	Ki	Ṭa	Tin	Nā	Tin	Nā
Dhā$_o^{oc}$	Ṭe^{xs}	Dhā$_o^{oc}$	Dhe$_o^{xs}$	Te^{xs}	Ṭe^{xs}	Dhā$_o^{oc}$	Ṭe^{xs}	Dhā	Ra	Dhā	Dhe	Te	Ṭe	Dhā	Ra
Dhin$_o^{os}$	Ge$_o$	Te^{xs}	Ṭe^{xs}	Tin^{ol}	Ge$_o$	Te^{xs}	Ṭe^{xs}	Dhā	Ge	Te	Ṭe	Tā	Ge	Te	Ṭe
Dhā$_o^{oc}$	Ge$_o$	Nā^{oc}	Ge$_o$	Dhin$_o^{os}$	Nā^{oc}	Ge$_o$	Nā^{oc}	Dhā	Ge	Nā	Ge	Dhin	Nā	Ge	Nā
Dhā$_o^{oc}$	Tin$_x^{os}$	Nā^{oc}	Dhā$_o^{os}$	Tin$_x^{os}$	Nā^{oc}	Dhā$_o^{oc}$	Tin$_x^{os}$	Dhā	Tin	Nā	Dhā	Tin	Nā	Dhā	Tin

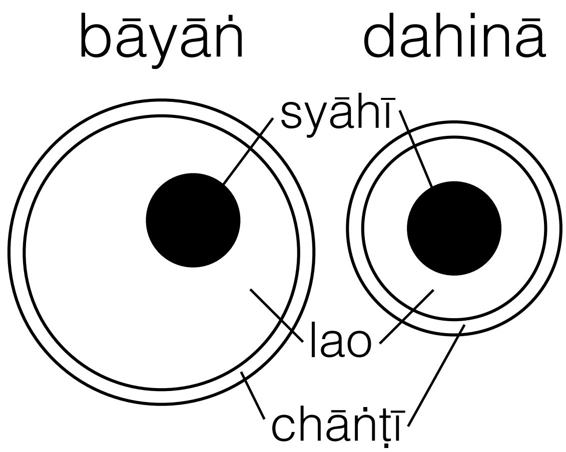


Figure 1. Schematic drawing of the tabla drum surface including the outer ring (chāṅṭī), the inner surface head (lao), and the patch (syāhī). The bāyāṅ is usually played with the left hand, the dahinā with the right hand.

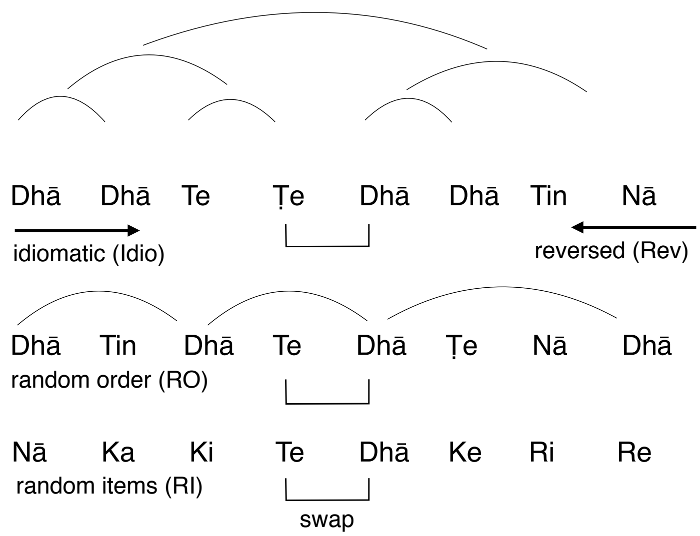


Figure 2. Example of the four sequencing conditions. An idiomatic sequence of bols and the corresponding reversed, random order, and random items conditions. Note that in all conditions, the same items swap positions in non-match trials.

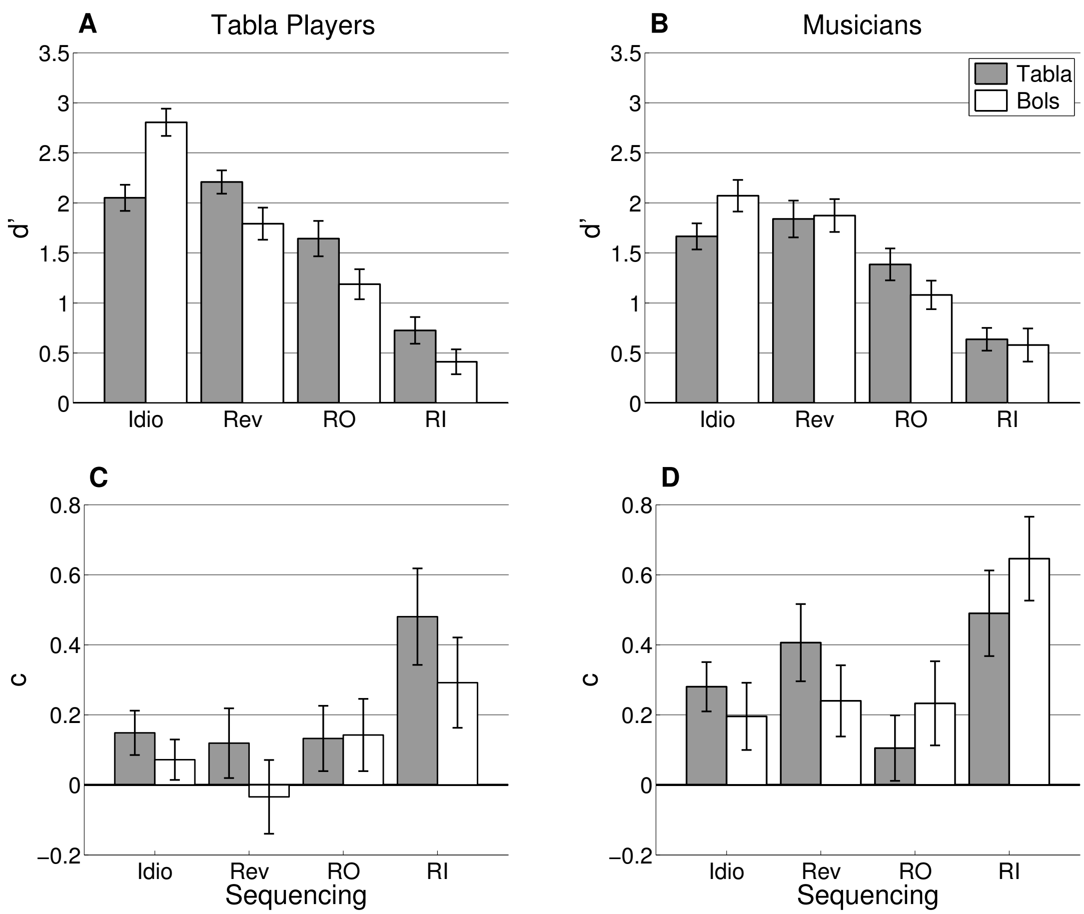
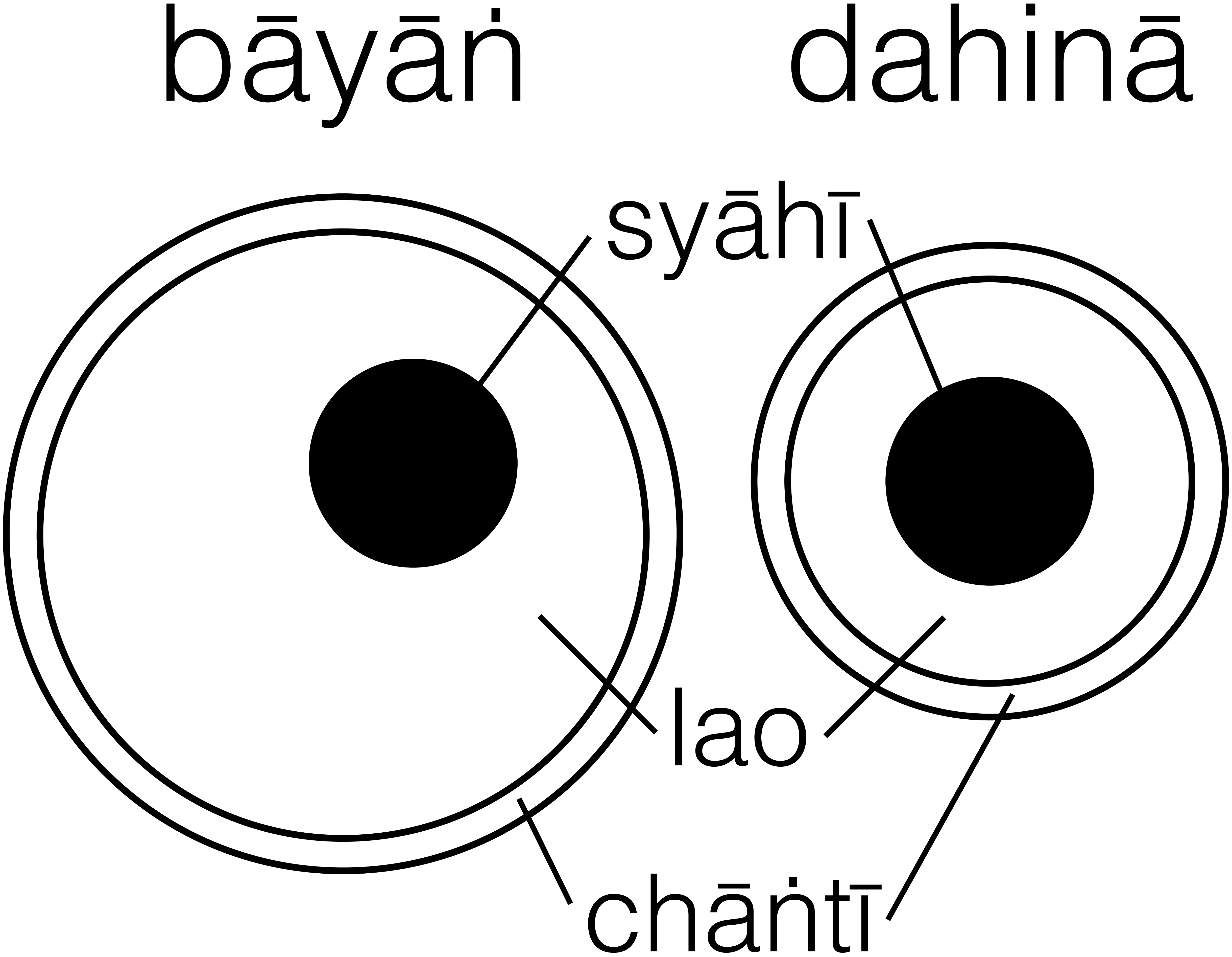
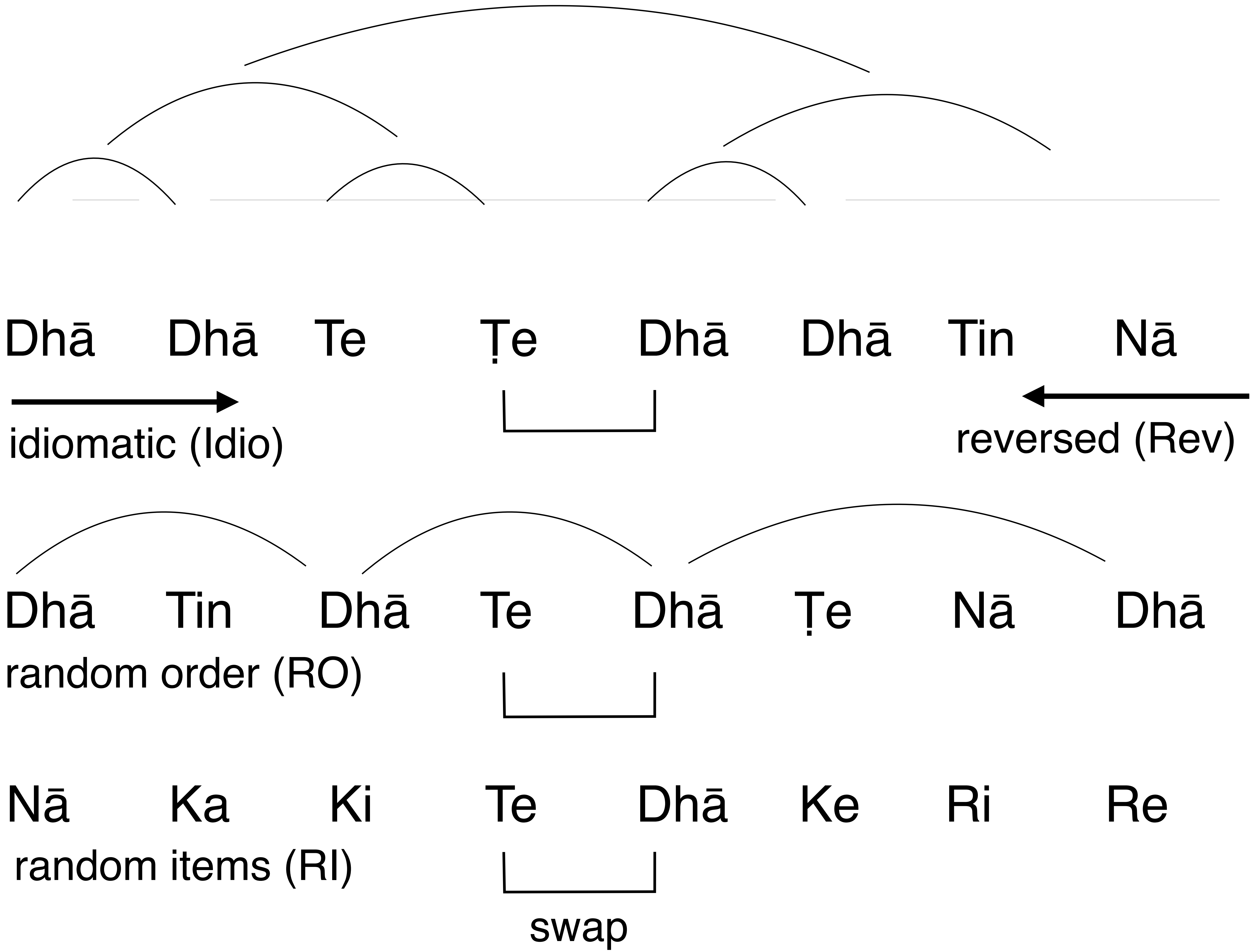


Figure 3. d' scores for tabla players (A) and musicians (B) for idiomatic sequences (Idio), reversed sequences (Rev), random order (RO), and random items (RI). Response bias as given by the criterion location c for tabla players (C) and musicians (D). Error bars display standard errors of the mean.

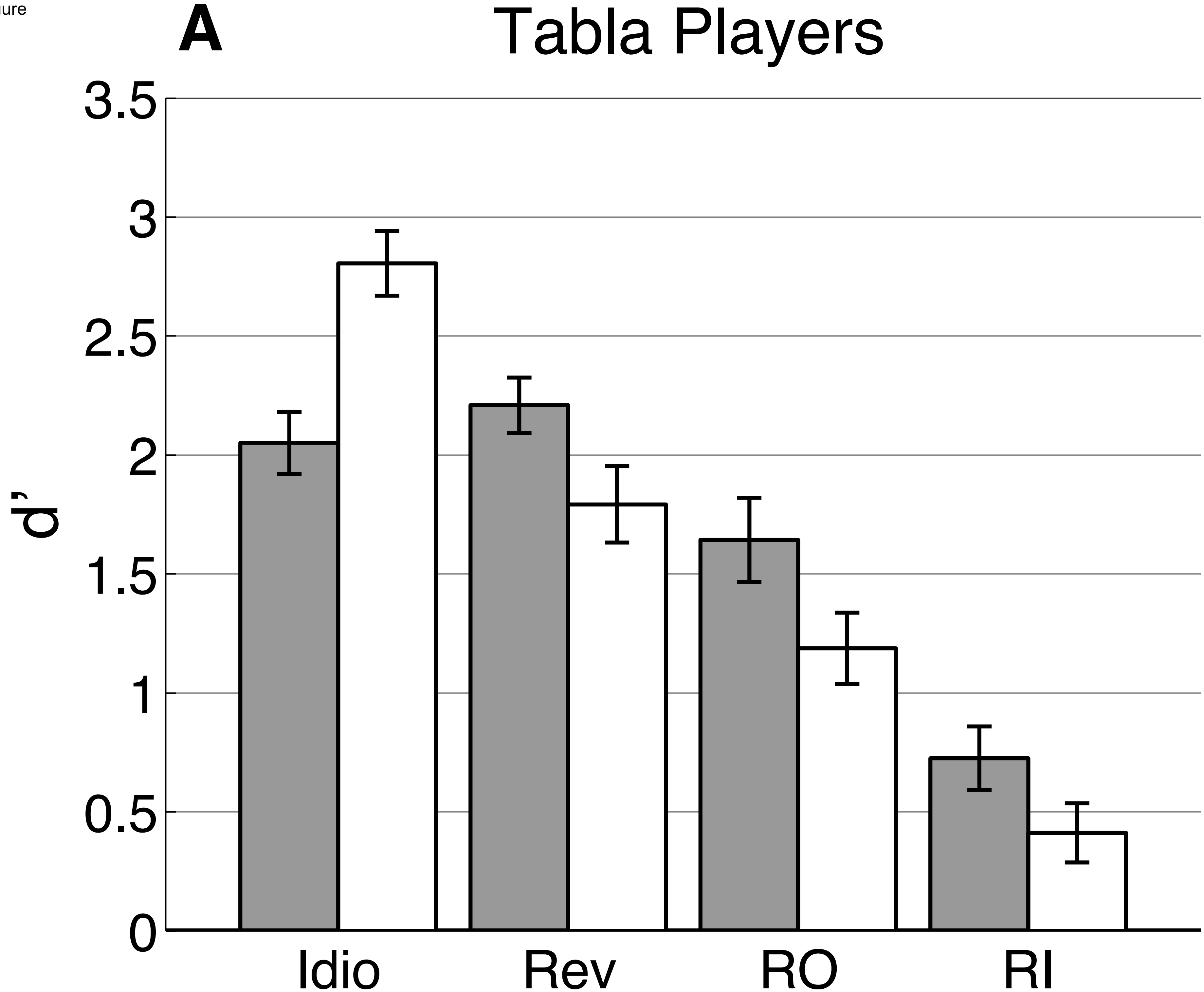
Figure



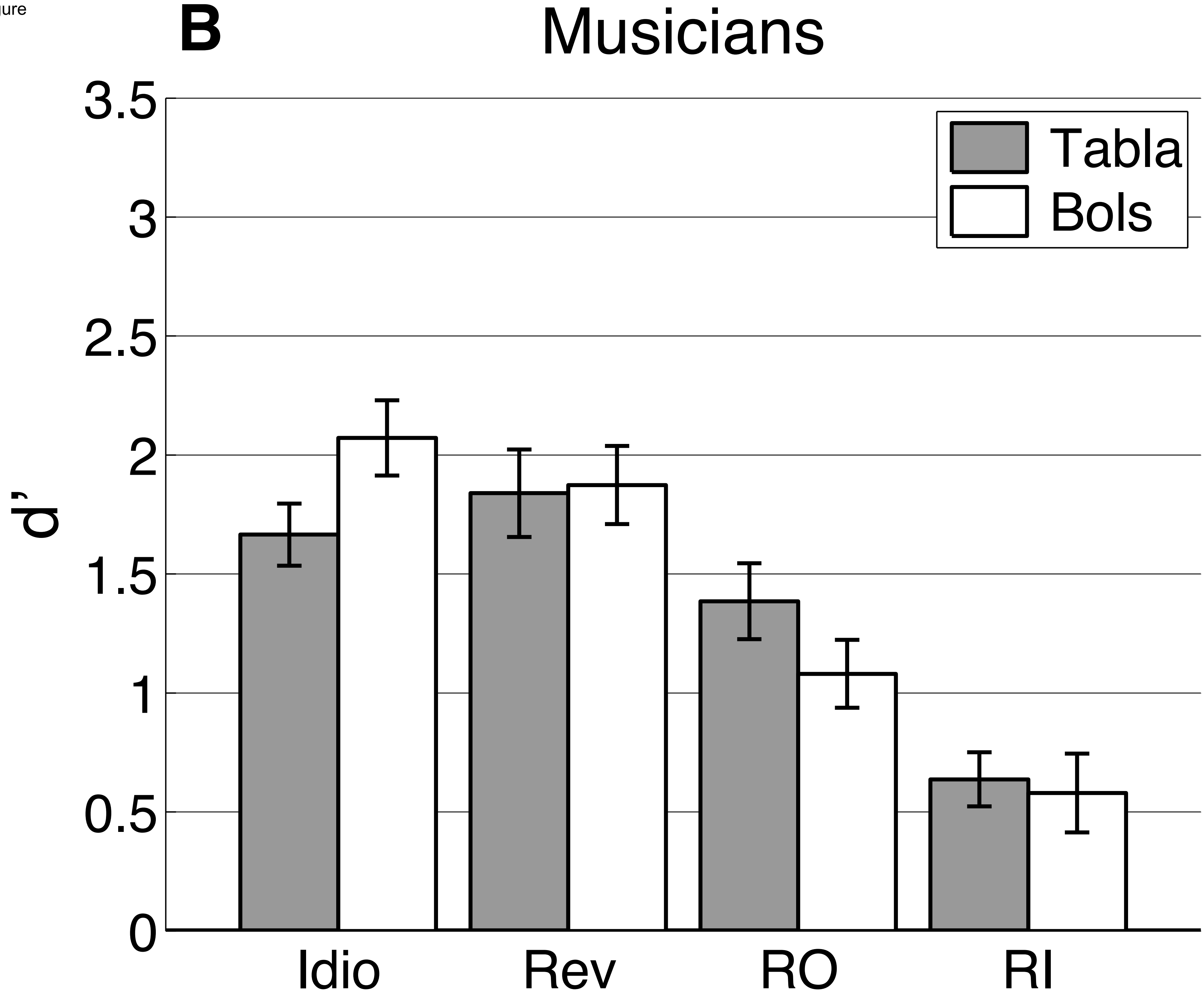
Figure


Dhā Dhā Te Ṭe Dhā Dhā Tin Nā
idiomatic (Idio)
reversed (Rev)
Dhā Tin Dhā Te Dhā Ṭe Nā Dhā
random order (RO)
Nā Ka Ki Te Dhā Ke Ri Re
random items (RI)
swap

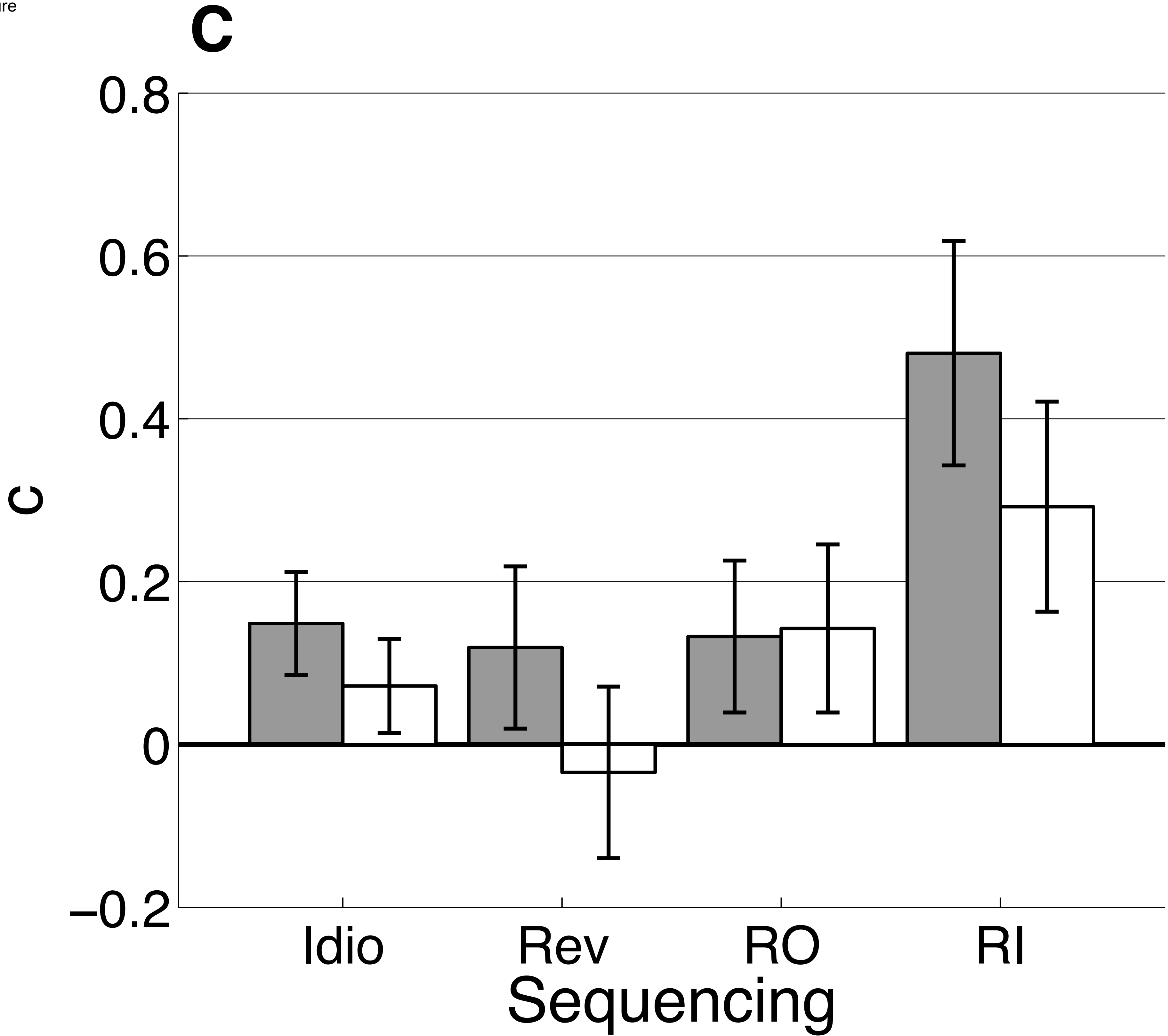
Figure



Figure



Figure



Figure