Research Article

Effects of Voice Onset Time on Ear Advantage in Persian Dichotic Listening Test

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Short running title: Effects of Voice Onset Time on Ear Advantage…

Highlights:
- VOT systematically modulates ear advantage in Persian dichotic listening
- Long-VOT stimuli override the typical right-ear advantage in dichotic tasks
- Auditory lateralization is dynamic and shaped by stimulus acoustic properties

ABSTRACT
Background and Aim: The dichotic listening test is widely used to assess hemispheric asymmetry and speech lateralization. The study investigated the effect of Voice Onset Time (VOT) on the perception of Consonant-Vowel syllables in the Persian dichotic listening task.

Methods: Three 36-word lists were constructed and categorized into four VOT conditions: short-short (SS), long-long (LL), short-left/long-right (SL), and long-left/short-right (LS). A total of 71 right-handed adults with normal hearing participated.

Results: The results showed a significant effect of VOT on percentage of correct responses and ear advantage. Long-VOT syllables were reported more frequently than short-VOT syllables in both ears. The strongest right-ear advantage was observed when long-VOT stimuli were presented to the right ear, whereas presenting long-

VOT stimuli to the left ear shifted performance toward the left ear, reversing the typical pattern. VOT also significantly affected the laterality index, with values shifting toward the ear receiving the long-VOT stimulus.
Conclusion: VOT, as a temporal feature of speech, plays an important role in shaping the ear advantage in dichotic listening. The results also suggest that auditory lateralization is influenced by stimulus characteristics rather than reflecting a fixed pattern.
Keywords: Dichotic listening, voice onset time, lateralization, consonant–vowel syllables

Introduction

The dichotic listening (DL) test is a valid non-invasive method for studying hemispheric asymmetry during the processing of speech stimuli [1, 2]. This test is based on the simultaneous presentation of specific auditory stimuli to both ears, and creating hemispheric competition [1, 3]. The test allows researchers to assess functional asymmetry and examine how specific acoustic features affect speech perception [4]. The dichotic listening test has its origins in early studies of auditory attention by Broadbent (5), and later adapted by Kimura for use in clinical and lateralization research [6, 7]. Building on this framework, Kimura's studies showed a strong right-ear advantage (REA) in right-handed individuals with normal hearing, which led her to present a neuroanatomical model to justify this phenomenon. REA has been explained by reduced contribution of ipsilateral pathways and more direct access of right-ear input to the left hemisphere. In contrast, left ear information must be transmitted from the right hemisphere to the left hemisphere through the corpus callosum. However, recent research has challenged the simplicity of this fixed structural model, suggesting that hemispheric lateralization is more dynamic and sensitive to stimulus-specific acoustic properties than originally assumed [1, 3, 8]. This shift in perspective highlights the need for further investigation of how specific acoustic variables modulate perceptual laterality, forming the basis of the current study.

While the structural model explains why speech is often processed in the right ear [9], it does not fully account for variability in ear advantage across stimulus types. For example, non-speech stimuli such as melodies often produce a left-ear advantage (LEA), suggesting that hemispheric asymmetry is influenced by factors beyond fixed anatomical pathways. This has led to the development of attentional models, proposed by Kinsbourne, which emphasize the role of dynamic attentional biases in modulating perceptual asymmetry [10]. In parallel, researches have demonstrated that DL outcomes are highly sensitive to stimulus acoustic properties. In particular, temporal features such as voice onset time (VOT) have been shown to systematically influence ear advantage, and may even reverse the typical REA [7, 11]. Cross-linguistic studies suggested that these effects may vary across languages. For example, Bedoin, Ferragne (12) suggest that phonetic features modulate hemispheric asymmetry differently in French, while Westerhausen, Põldver (8) observed a weaker effect of VOT-related contrasts in Estonian compared to Norwegian. Taken together, these findings suggest that auditory laterality in DL reflects a dynamic interaction between structural constraints, attentional mechanisms, and language-specific phonetic properties, rather than a fixed neural processing model.

VOT refers to the temporal interval between the onset of plosive consonant release and the start of vocal folds' vibration, which serves as a critical acoustic cue that helps distinguish phonetic categories [13, 14]. Plosive voiced consonants /b/, /d/, /g/ are typically characterized by shorter VOTs, and voiceless plosive consonants /k/, /t/, /p/ show longer VOTs (see Methods section for details) [7, 11, 13]. This temporal difference will help listeners to categorize phonetic contrasts that originated from the same place of articulation [15, 16]. Research suggests that VOT has been shown to affect perceptual outcomes in DL tasks. Experimental studies reported that systematic manipulation of VOT can modulate, in some cases reverse, the typical REA observed for speech stimuli [7, 11]. These findings suggest that temporal acoustic cues may be able to contribute to bottom-up processes on auditory laterality. However, despite the important role of VOT in speech processing, its effect on laterality processing is incompletely understood at a cross-linguistic level. Because VOT patterns vary across languages [13], it is unclear whether the effect on ear advantage reflects a universal auditory mechanism or is shaped by language-specific phonological structures.

Findings regarding the role of VOT in DL have been inconsistent. Early studies often relied on simplified models of hemispheric lateralization, overlooking the complex interaction between acoustic cues and perceptual processing. More recent studies have challenged these assumptions by demonstrating that acoustic cues, particularly temporal features such as VOT, play a more active role in shaping ear advantage than previously assumed [7, 11]. Although these findings have been effective, most studies have been conducted in Germanic languages such as English and Norwegian [7, 8, 11], with fewer studies examining other languages. This imbalance represents an important research gap because the phonetic realization of VOT varies across languages [13]. Consequently, it remains unclear whether the effect of VOT on ear advantage reflects a general auditory mechanism or is influenced by language-specific phonological characteristics. To date, this question has received little attention in Persian. Therefore, examining the effect of VOT in Persian provides an opportunity to determine whether previously reported findings can be generalized beyond the languages studied. Therefore, the present study aimed to investigate the effect of VOT on ear advantage and laterality in a Persian DL task using consonant-vowel (CV) stimuli.

Methods

Participants

The study population included 71 young individuals (38 females and 33 males) with normal hearing in the age range of 19 to 28 years (mean age of 23.7 ± 2.46 years). The required sample size was estimated based on a repeated-measures analysis of variance (RM ANOVA). Assuming an effect size of 0.15 based on previous studies, a significance level of 0.05, a statistical power of 0.80, and sphericity of the data, the minimum required sample size was calculated to be 67 participants. The final sample exceeded this requirement to account for potential participant attrition. The participants mastered Persian as their native language, had no history of neurological diseases, and had normal hearing thresholds within the frequency range of 500 to 4000 Hz. The participants were right-handed, as confirmed by the Edinburgh handedness inventory [17]. Those who did not fulfill the inclusion criteria were excluded from the study.

Stimuli

The Persian version of the Bergen CV dichotic test, which was developed and validated by Jafari et al. (18), was used in the present study. All sounds were recorded with a man's voice and a constant intensity and tonality. The synchronization was assessed using Adobe Audition 2019 software to ensure the simultaneous start of the syllable in the right and left channels based on the consonant release time, but their endings remained unmanipulated.
The test included a set of meaningless consonant-vowel syllables (including six plosive consonants /g, k, t, d, b, p/ with the vowel /a/) that were presented dichotically to both ears (e.g., /ba-ga /, /ta-ga/, etc.). The total number of stimuli was 108 items that were randomly divided into three lists of 36. Six items were identical syllable pairs (e.g., /ba-ba/) that were not included in the data analysis and were presented to familiarize the participant with the test process. As a result, the maximum score for each list was 30. Due to the fact that our aim was to assess the effect of VOT, the stimuli could not be randomly presented to both ears and had to be classified according to VOT. Based on acoustic analysis presented by Bijankhan and Nourbakhsh (13), the VOT values of the Persian CV syllables were as follows: for voiced consonants, mean VOTs were 2.8 ms for /ba/, 7.1 ms for /da/, and 14.5 ms for /ga/. For voiceless consonants, mean VOTs were 68.7 ms for /pa/, 79.5 ms for /ta/, and 97.8 ms for /ka/. These values are consistent with the expected temporal distinction between voiced (short VOT) and voiceless (long VOT) stop consonants reported in previous studies [7, 11]. Therefore, it was possible to present stimuli in four VOT modes (Table 1): 1) presenting short-VOT syllables (SS) to both ears (six pairs), 2) presenting long-VOT syllables (LL) to both ears (six pairs), 3) presenting short-VOT syllables to the left ear and long-VOT syllables to the right ear (SL; nine pairs), and 4) presenting long-VOT syllables to the left ear and short-VOT syllables to the right ear (LS; nine pairs).

Procedure

All the syllables were categorized into three 36-item lists (including 30 pairs of main stimuli and six pairs of training stimuli) and were presented dichotically to the participants through Sennheiser headphones connected to a laptop. Before testing, the presentation level was adjusted individually for each participant to ensure a comfortable listening level (55–75 dB SPL). The order of presentation of the three lists was randomized across participants to minimize possible order effects. To increase the accuracy of stimulus presentation and facilitate data analysis, a software was designed to be able to present the lists to the individuals and collect the participants' responses in tables that were exportable. The stimuli were displayed as selectable written options (upside-down U shape) on the screen and were equally distant from a single point in the center. The participants selected their desired responses among available syllables by moving the mouse pointer. After each response, the mouse pointer automatically returned to the center of the screen to make sure if the response time was roughly similar for each stimulus, and the effect of confounding factors was minimized.

The test was performed in three attention modes: non-forced (NF), forced right (FR), and forced left (FL). To ensure the validity of test results and minimize the possibility of giving random responses, each list was presented twice in a row to each participant. Initially, the NF mode was presented, during which the individual received one of the syllables /ga, ka, ta, da, pa, ba/ in each ear simultaneously. The participant was instructed to choose the more clearly heard syllable on the screen when receiving two different syllables in each ear and to select only one syllable at a time. Based on the percentage of correct responses for the right and left ears, the non-focused laterality index (NFLI) was calculated using the formula: $NFLI = (RE-LE)/ (RE+LE) \times 100$. In the present study, NFLI was used as the baseline indicator to calculate and interpret the changes in laterality index (LI) in the attention modes. In addition, the NFLI was used as an inclusion criterion, and only those who showed right ear advantage in the NF mode were included in the study so that the results be comparable with the findings of the other languages. In the FR mode, the participant was asked to pay attention only to the stimuli in the right ear and ignore those of the left ear. In the FL mode, the individual was asked to pay attention only to the stimuli in the left ear and ignore those heard in the right ear. The three attention conditions (NF, FR, and FL) were included to maintain consistency with the standard dichotic listening paradigm and to facilitate comparison with previous studies using the same protocol. As the primary aim of the present study was to examine the effect of VOT rather than attentional modulation, attention condition was not analyzed as a separate experimental factor. For the main analyses, performance was averaged across attention conditions to focus on the effect of VOT as a stimulus-driven factor.

Data analysis

In the present study, descriptive statistics, including central tendency indices such as mean and dispersion indices such as standard deviation, were used to describe the data. For inferential analysis, repeated-measure analysis of variance was used to assess the effects of the VOT mode on laterality. Data analysis was performed using SPSS 17statistical software at the significance level of $\alpha < 0.05$.

Results

Figure 1 presents an RM ANOVA to assess the effects of VOT conditions (SS, LL, SL, LS) and Ear (left, right) on the number of correct responses. Interpretations of ear advantage across VOT conditions were supported by comparisons of correct-response percentages between the two ears. Mauchly's test indicated violation of the sphericity assumption for VOT ($W = .639$, $p < .001$) and VOT × Ear ($W = .465$, $p < .001$); therefore, Greenhouse–Geisser corrected degrees of freedom were used. The analysis revealed a significant main effect of VOT ($F(2.49, 174.54) = 112.63$, $p < .001$, partial $\eta^2 = .617$), a significant main effect of Ear ($F(1, 70) = 70.82$, $p < .001$, partial $\eta^2 = .503$), and a significant VOT × Ear interaction ($F(1.97, 137.88) = 149.26$, $p < .001$, partial $\eta^2 = .681$). The significant interaction showed that ear advantage varied across VOT conditions. Specifically, in the SL condition (short-VOT in LE, long-VOT in RE), participants showed a clear REA, with higher percentage of correct responses in the RE compared to the LE (Mean ± SD = 66.88 ± 13.12 vs. 18.7 ± 12.64). The LS condition (long-VOT in LE, short-VOT in RE) demonstrated a reversal of this pattern, with superior performance in the left ear (Mean ± SD = 57.02 ± 13.86 vs. 26.19 ± 14.27). Performance in the LL and SS modes indicated a consistent REA, with higher accuracy observed in the RE across both conditions. Bonferroni-adjusted post-hoc comparisons (Table 2) revealed significant differences between all VOT conditions (all $p < .001$), except between the LS and SL conditions ($p = .072$), for which no significant difference was observed.

Figure 2 presents the laterality index across VOT conditions. An RM ANOVA was performed to assess the effect of VOT conditions on LI. Mauchly's test indicated a violation of the sphericity assumption ($W = .390$, $p < .001$); therefore, Greenhouse–Geisser corrected degrees of freedom were used. The analysis revealed a significant main effect of VOT conditions ($F(1.83, 127.77) = 153.66$, $p < .001$, partial $\eta^2 = .687$). The SL condition showed the strongest REA (Mean ± SD = 0.56 ± 0.29), followed by the LL (0.18 ± 0.2) and SS (0.17 ± 0.22) conditions. In contrast, the LS condition (-0.37 ± 0.33) indicating a left ear advantage. Post-hoc tests with Bonferroni correction showed significant differences in all paired comparisons ($p < .001$) except between LL and SS modes ($p = 1.00$).

Discussion

This study examined the effect of VOT on ear advantage and laterality index in a Persian dichotic listening task. The results showed that VOT conditions had a significant effect on how sounds were perceived. CV syllables with long VOT were reported more frequently than those with short VOT in both ears. The strongest REA was observed in the SL condition, where the long-VOT stimulus was presented to the right ear. In contrast, presenting the long-VOT stimulus to the left ear (LS condition) shifted performance toward the left ear, reversing the typical pattern from REA to LEA. Overall, these findings suggest that VOT can substantially influence the magnitude and direction of ear advantage in individuals exhibiting a typical REA pattern.

The results of this study show that VOT significantly modulates ear advantage in dichotic listening. As seen in Figure 1, performance changed across the four VOT conditions. When a long-VOT syllable was presented to the right ear (SL condition), the highest number of correct responses was observed in the right ear, showing a strong REA. In contrast, when the long-VOT syllable was presented to the left ear (LS condition), performance shifted toward the left ear, and a clear LEA was observed. In the matched conditions (LL and SS), a right-ear advantage was still present, but it was smaller compared to the SL condition. One possible explanation is related to the perceptual strength of long-VOT syllables. Compared to short-VOT sounds, long-VOT syllables have a longer delay between release and voicing onset and a longer interval of aspiration noise [14], which may provide a more robust perceptual cue. Recent studies show that VOT as an important temporal cue in speech perception is processed based on fine temporal differences in the acoustic signal [19, 20]. This means that longer VOTs provide a more noticeable temporal cue, which can make them easier to detect [19]. Under dichotic conditions, where two signals compete, the auditory system may favor the signal that is easier to detect and maintain [1, 10]. This could explain why long-VOT stimuli were reported more often in both ears and why the ear receiving the long-VOT stimulus showed higher performance. Similar interpretations have been reported by Rimol, Eichele (11) and Moncrieff and Dubyne (7), who also found that long-VOT syllables tend to dominate during dichotic competition.

A second explanation relates to temporal competition between the two auditory inputs. When short- and long-VOT stimuli are presented at the same time, they differ in their timing, which can affect how one signal is selected. Long VOT syllables have a longer aspiration phase, which may overlap with the shorter signal in the opposite ear, and reduce its perceptual clarity. This idea is in line with earlier studies on temporal masking and interaural competition, which suggest that temporal offsets between signals can alter their relative perceptual dominance [21, 22]. In the LS condition, the long-VOT signal in the left ear may gain a temporal advantage over the short-VOT signal, leading to more responses from the left ear. This effect does not reflect a true change in hemispheric dominance, but rather a stimulus-driven effect. These findings suggest that ear advantage is influenced by both structural asymmetry and temporal properties of the stimuli.

This pattern was also reflected in the laterality index. The laterality index shifted toward the ear receiving the long-VOT stimulus (Figure 2). In the LS condition, where long VOT was presented to the left ear, the laterality index showed a clear shift toward LEA. In contrast, when long VOT was presented to the right ear (SL condition), the REA became stronger. In the LL and SS conditions, the laterality index remained positive, indicating a weaker REA. This consistency between performance and laterality index suggests that the effect of VOT is not limited to a single behavioral measure but may reflect a stable pattern of lateralized processing. In dichotic listening research, the LI has been widely used as a reliable measure of hemispheric asymmetry. For example, Hugdahl (1) showed that LI provides a reliable index of ear advantage, although it can be influenced by task conditions. Similarly, Westerhausen (3) discussed the role of dichotic listening measures, including LI, in assessing hemispheric asymmetry and emphasized the importance of ensuring reliable measures and controlling for factors that influence performance across conditions. These findings support the idea that the effect of VOT observed in the present study reflects a systematic influence on auditory processing rather than a result of a particular measurement method.

Although the present results show a strong effect of VOT on ear advantage, this effect may vary across languages. For example, Westerhausen, Põldver (8) reported a weaker influence of voicing-related cues on laterality in Estonian compared to Norwegian speakers. This suggests that the role of VOT in shaping laterality depends on language-specific phonological characteristics. In addition, studies in French have shown that VOT is not the only cue involved in speech perception. Bedoin, Ferragne (12) showed that other acoustic features, such as formant transitions, also affect speech perception. These findings suggest that although VOT plays an important role, speech perception is influenced by multiple acoustic cues rather than a single factor.

The present findings have important implications for clinical dichotic listening tests. First, the results show that temporal features such as VOT can influence ear advantage, which means that clinicians should consider stimulus characteristics when interpreting test results. For example, a shift toward the left ear may not always reflect a true neurological difference, but may instead be influenced by the acoustic properties of the stimuli [11]. Second, the findings suggest that the balance of VOT across test items is important. If a test includes more long-VOT stimuli in one ear, it may bias performance toward that ear and potentially affect the interpretation of test outcomes [7]. Finally, these results may be useful for designing more reliable dichotic listening tools by ensuring that temporal features are controlled and balanced across conditions, which can support more accurate clinical interpretation of auditory processing and lateralization [1].

This study has several limitations that should be considered. First, the role of attention was not directly analyzed, even though different attention conditions were included in the design. Previous studies have shown that attention can influence dichotic listening performance [10], and future research should examine how attention interacts with VOT more directly. Second, the study included only young adults with normal hearing, which limits the generalizability of the findings to other populations such as children, older adults, and clinical groups. Previous research has shown that factors such as age and hearing status can influence dichotic listening performance, suggesting that the observed effects may differ in other populations [1]. Third, the study focused only on Persian stimuli, and cross-language differences were not tested directly. Given that previous studies have reported differences across languages [8, 12], further research is needed to confirm whether the present findings can be generalized to other linguistic contexts.

Conclusion

The present study showed that voice onset time significantly affected ear advantage and laterality index in a Persian dichotic listening task. Performance consistently shifted toward the ear receiving the long-VOT stimulus. Presenting the long-VOT stimulus to the right ear strengthened the right-ear advantage, whereas presenting it to the left ear shifted performance toward a left-ear advantage. These findings highlight the importance of controlling and balancing voice onset time across ears when designing dichotic listening tests and interpreting their results.

Ethical Considerations

Compliance with ethical guidelines

All participants provided written informed consent, and the study was approved by the Research Ethics Committee of the School of Rehabilitation, Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC1399.343).

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Authors' contributions

AM: Methodology, investigation, formal analysis, visualization, data curation, writing-original draft, writing-review and editing; MMA: Data collection, formal analysis, data curation, writing-review and editing; YP: Data collection; BMB: Writing-review and editing. AN: Conceptualization, methodology, investigation, supervision, writing-review and editing, project administration. All authors contributed to the article and approved the submitted version.

Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that this study had no financial or commercial relationships that could be seen as a conflict of interest.

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Table 1. All possible states of voice onset time-based classification

Short-Short	Short-Long	Long-Short	Long-Long
ba-da	ba-pa	pa-ba	pa-ta
ba-ga	ba-ta	pa-da	pa-ka
da-ba	ba-ka	pa-ga	ta-pa
da-ga	da-pa	ba-ta	ta-ka
ga-ba	da-ka	ta-da	ka-pa
ga-da	da-ta	ta-ga	ka-ta
-	ga-pa	ka-pa	-
-	ga-ka	ka-ta	-
-	ga-ta	ka-ga	-

Note. This note applies to all four voice onset time conditions presented in the table. Each pair shows the syllables presented to the left and right ears, respectively. “long” and “short” refer to voice onset time categories of the consonants. Dashes (-) indicate that no valid combination exists for that condition.

Table 2. Bonferroni-adjusted post-hoc pairwise comparisons between voice onset time conditions

Comparisons	Mean difference±SE	p
LS-SL	–1.19 ±0.46	=0.072
LS-LL	–4.43 ±0.47	<0.001
LS-SS	–6.60 ±0.38	<0.001
SL-LL	–3.24 ±0.44	<0.001
SL-SS	–5.41 ±0.32	<0.001
LL-SS	–2.17 ±0.31	<0.001

Note. The first and second letters indicate the voice onset time category of the stimuli presented to the left and right ears, respectively. L = long voice onset time; S = short voice onset time; SE = standard error.

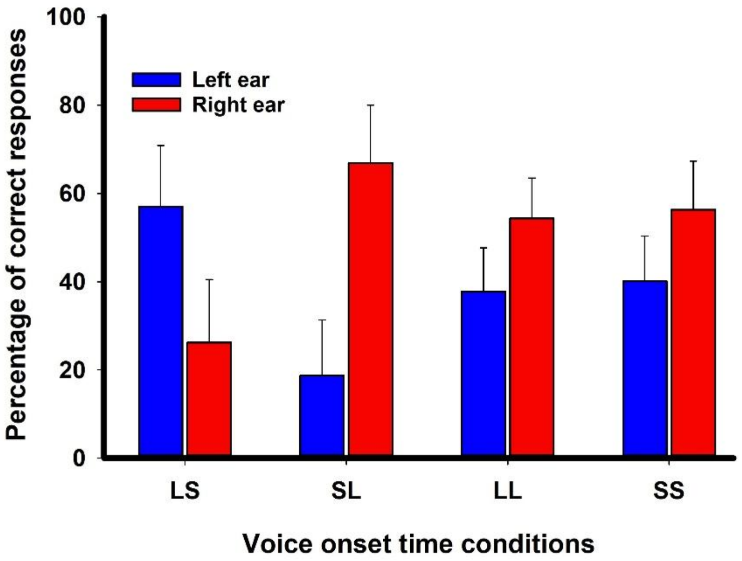

Figure 1. Mean percentage of correct responses in the left and right ears across the four voice onset time conditions. In each condition, the first and second letters represent the stimuli presented to the left and right ears, respectively. Error bars represent standard deviation. LS; long-short, SL; short-long, LL; long-long, SS; short-short

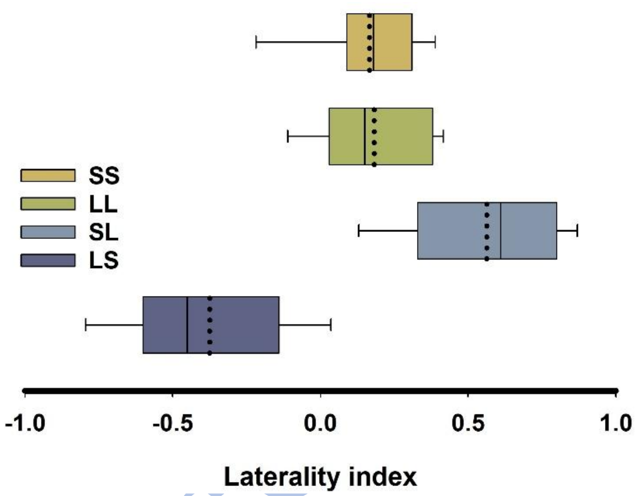

Figure 2. Laterality index across the four voice onset time conditions. Positive laterality index values indicate right-ear advantage, whereas negative values indicate left-ear advantage. The solid line within each box represents the median, and the dotted line represents the mean. SS; short-short, LL; long-long, SL; short-long, LS; long-short.