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Left visual-field advantage in the dual-stream RSVP task and reading-direction: A study in three nations

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ABSTRACT

In the dual-stream Rapid Serial Visual Presentation task, a stream of stimuli containing two target stimuli is rapidly presented left and right. In previous studies, the second target was better identified in the left than in the right hemifield. In all those studies, alphanumeric stimuli were used both as targets and distracters. We examined to what extent this left visual-field advantage is dependent on reading-direction. The task was performed by Germans (with Latin characters), Israelis (with Latin and Hebrew characters) and Taiwanese (with Latin and Chinese characters). If caused by overlearnt associative links between Latin characters and left-to-right reading, the prominent left visual-field bias should be reversed in Hebrew and disappear in Chinese. Furthermore, if caused by direction of reading in the participant's native language, the left visual-field advantage in Latin conditions should be larger in Germans than in Israelis and Taiwanese. A left visual-field advantage was always observed, though slightly smaller in Hebrew and in Chinese, and there was no difference in the Latin conditions between the three nations. Therefore, it seems that the left visual-field advantage in speeded target identification is not primarily caused by the left-to-right reading-direction, but may be a combined effect resulting from the asymmetric organization of general mechanisms of visual processing and from stimulus-induced preferences.

The dual-stream Rapid Serial Visual Presentation task (dual RSVP) is a variant of the attentional blink (AB) paradigm. Two streams of stimuli are rapidly (10/s) displayed in the right and left visual hemifields simultaneously. Embedded among distracting stimuli, the first and second targets (T1 and T2) may appear on the right or left side with equal probability. Analogously to the AB paradigm, T1 is usually identified with high accuracy, whereas T2 identification depends on the lag between the two targets and their locations. Identification rates are high at short lag for targets presented in the same hemifield, but much lower for targets presented in opposite hemifields. For longer lags this difference decreases (Holländer, Corballis, & Hamm, 2005; Verleger et al., 2009; Verleger et al., 2010). Of interest, in this task a strong advantage for the left visual hemifield has been reported: T2 was generally much better identified when appearing in the left than in the right hemifield, especially when the two targets were presented in different locations (Holländer, Corballis, et al., 2005; Holländer, Hausmann, Hamm, & Corballis, 2005; Scalf, Banich, Kramer, Narechania, & Simon, 2007; Verleger et al., 2009; Verleger et al., 2010) even when participants' gaze was rigorously controlled by means of an infrared eye-tracker (Verleger et al., 2009).

The left visual-field advantage (LVA) in the dual RSVP task may reflect some constant, relatively "hard-wired" difference between hemispheres. For example, an LVA was likewise obtained by Hellige and Webster (1979) already when presenting single letters followed by a mask, which they ascribed to some better ability of the right hemisphere in singling out events in time. Additionally, in a series of experiments, Hellige, Cox, and Litvac (1979) underlined the notion that the left hemisphere may be easily overloaded by perceptual and memory demands, which may also play a role in the present task, where many stimuli are presented and T1 has to be memorized. "Hard-wired" reasons for the LVA may also relate to the interaction of both hemispheres. Specifically, the right-hemisphere might be dominant for the control of attention, implying that it exerts inhibition on the left hemisphere (Kinsbourne, 1993) in demanding situations like the present RSVP task (Scalf et al., 2007).

However, the left visual-field advantage in dual RSVP might also be due to less general factors, which have been demonstrated to

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affect performance in several visuospatial tasks. For example, as reviewed by Jewell and McCourt (2000), the left visual-field bias in the line bisection task (Hausmann, Waldie, & Corballis, 2003; McCourt & Jewell, 1999) is modulated by multiple factors, such as age, sex, laterality as well as motor factors like the limb used to bisect lines or the direction of visual scanning. The left visual-field bias is also modulated by alertness and attentional load (Manly, Dobler, Dodds, & George, 2005; Pérez, Pentón, & Valdés-Sosa, 2008). For example, Pérez and colleagues (Pérez et al., 2008; Pérez et al., 2009) had participants decide whether a left or a right stimulus had appeared first and inserted this pair of stimuli as the T2 in an attentional blink task. Under low attentional load (T1 was ignored or the lag between T1 and T2 was long) the left target was overestimated as the first one (Pérez et al., 2008) or there was no difference between left and right targets (Pérez et al., 2009). Under high attentional load (the lag between T1 and T2 was short) the right target was overestimated as the first one.

One possibility tested in the present study is that the LVA in dual RSVP is a consequence of participants' reading habits, possibly induced by the stimulus material, since in all the above-reported studies letters were used as T1 and as distractors. This hypothesis seems to be counterintuitive. Rather, one might speculate that learned reading-direction should induce some tendency to focus first on the left hemifield and then move to the right hemifield, analogously to the direction of reading Latin-letter scripts (see Spalek & Hammad, 2004, 2005). If this were true, T2 would be better identified when on the right after a left T1. This, however, is opposite to the effect actually obtained. But spatial attention may be affected by reading in developing a habitual bias towards the usual point of departure of script (Han & Northoff, 2008): left-to-right reading may bias attention towards the left hemifield, and right-to-left reading may facilitate attention towards the right hemifield. This suggestion is consistent with several studies, where biases in visuospatial and attentional tasks depended on the side at which participants habitually started reading (Abed, 1991; Chokron & Imbert, 1993; Chokron, Bernard, & Imbert, 1997; Eviatar, 1995; Zivotofsky, 2004). For example, in the line bisection task, French participants (left-to-right reading) tended to mark the subjective middle of the line on the left from the objective middle, whereas Israeli participants (right-to-left reading) put marks on the right from the objective middle (Chokron & De Agostini, 1995). Analogously, left-to-right scanning of lines to be bisected produced a leftward bias and right-to-left scanning produced a rightward bias (Chokron, Bartolomeo, Perenin, Helft, & Imbert, 1998). In a letter-matching task, Eviatar (1995) observed that for English-readers it was more difficult to actively ignore the irrelevant stimulus in the left hemifield and for Hebrew-readers in the right hemifield.

Along these lines, the present study investigated whether the LVA in dual RSVP can be simply explained by reading-direction, as either primarily used by participants in their daily lives or as specifically induced by the letter stimuli. Using the same version of the task as Verleger et al. (2009), we conducted three experiments. T2 was always selected from the digits 1–6, but the character set from which T1 and the distracters were selected depended on participants' native language or were selected from Latin alphabet. Experiment 1 was conducted in Germany where reading is learned with Latin script written from left to right, Experiment 2 in Israel where Hebrew is the primary language which is read from right to left, and Experiment 3 in Taiwan where Chinese is the primary language which is read from top to bottom.[1] Using these data, we tested two versions of the reading-direction hypothesis. The hypothesis of stimulus-induced reading-direction states that it is the use of the letter stimuli that might induce preferences in focusing attention on the right or left hemifield. According to this prediction, the left-T2 bias should again occur in the Latin-alphabet condition, no difference between left T2 and right T2 should occur in the Chinese condition, and a right-T2 bias should appear in the Hebrew condition. In Latin conditions the left-T2 bias should be of the same size for all participants, because Israelis and Taiwanese, as university students, have experience with reading Latin scripts. The hypothesis of habitual reading-direction states that participants develop a bias to shift their attention with any stimuli. According to this prediction, in addition to the right-T2 bias in Hebrew and no bias in Chinese, in Latin conditions the left-T2 bias should be weaker in Taiwanese and Israelis than in Germans, because the latter participants have acquired a scanning strategy different from left-to-right reading by long-term experience in reading their primary language. In contrast, replication of the left-T2 bias in all conditions will be interpreted according to the "hard-wired" hypothesis of LVA.

Furthermore, by varying the lag from T1 to T2 we wished to examine the time course of any such reading influences, insofar they are triggered by T1. Following Müller and Rabbitt (1989; cf. Brignani, Guzzon, Marzi, & Miniussi, 2009, for more recent evidence) factors that exert their influence in automatic and reflexive ways should have their strongest effects at short lags, and factors that affect behavior via controlled processes should have their strongest effects at longer lags.

1. Method

1.1. Participants

Twenty-six students (13 males) from the University of Lübeck participated in Experiment 1 (E1), 28 students (14 males) from the Hebrew University of Jerusalem in E2, and 26 students (12 males) from the National Chung Cheng University of Taiwan in E3. Their ages were 20–28 years (mean = 24.0, SD = 2.7) in E1, 20–43 years (mean = 25.6, SD = 4.2) in E2, and 19–29 years (mean = 21.2, SD = 2.3) in E3. All participants were paid for their time or (some in E2) received course credit. All studies had been approved by the local ethics committee. Written consent was obtained after the experimental procedure was explained. All participants reported normal or corrected-to-normal vision, normal color vision, and no history of neurological disorders. They were all right-handed, as examined by the Edinburgh Handedness Inventory, with scores of 97 ± 3.4 (range 90–100) in E1 and of 82 ± 17.7 (range 60–100) in E3. An abbreviated 5-item version of the Edinburgh Handedness Inventory was used in E2, with scores of 94.3 ± 17.1 (range 20–100) when extrapolated to the usual scores. In E1, six participants were rejected from analysis due to high error rates in identifying T1 and T2 or because of eye movements (which were measured in all E1 participants by electrooculography). In E1 all participants were native German speakers, in E2 native Hebrew or bilingual Hebrew and Arabic speakers (Arabic, like Hebrew, is read from right to left) and in E3 native Chinese speakers. Being university students, both Israeli and Taiwanese participants had experience with reading Latin scripts, but did not use English in their daily lives.

1.2. Stimuli and apparatus

The task is illustrated in Fig. 1 for the Latin condition. Two simultaneous sequences of black capital letters were rapidly presented left and right from the fixation point. The task was to identify two targets among the black letters. Stimuli were 8.5 mm wide and 11 mm high ($0.5^\circ \times 0.6^\circ$ visual angle) and were presented on a white background on a 17" screen driven with 100 Hz at about 1.2 m from

[1] In the past, Chinese was read strictly from top to bottom and from right to left, however, in modern days, most Chinese documents are read from left to right, except Chinese novels and Chinese literature.

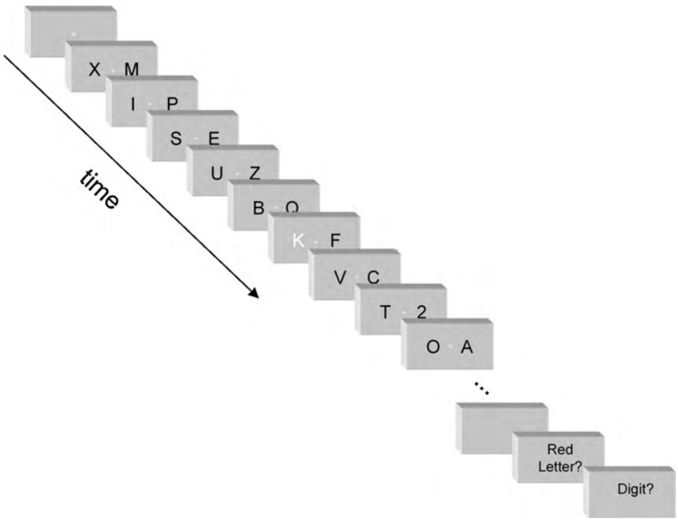

Fig. 1. Sequence of events in a single trial (see Section 1). The red color of T1 is replaced here by white.

the participants' face. Each frame in the sequence consisted of a pair of stimuli presented right or left from fixation, with the inner edge of stimuli 10 mm from fixation (0.6°). Fixation was marked by a small red cross (0.1° × 0.1°) at the center of the screen. Each frame was presented for 130 ms, immediately followed by the next frame. A trial consisted of 12–20 frames, as detailed below. In each trial there were two different targets: the first target (T1) was a red letter (in the Latin condition D, F, G, J, K, or L). The second target (T2) was a black digit (1, 2, 3, 4, 5, or 6). The set size of six targets was chosen to be large enough to decrease the chance of making a correct guess and to be small enough so the task of entering the response on the keyboard would not be too complex. The distracter set consisted of all other letters in black. Presentation® software, version 12.1, was used for experimental control (Neurobehavioral Systems Inc.).

In E1, only this Latin version was used. In E2 and E3, in addition to the Latin condition, a Hebrew (E2) or Chinese (E3) alphabet condition was used in a separate block. For the Hebrew condition, the target T1 was one of the letters "Zain", "Samekh", "Bet", "Mem", Tsadi "and" Tav" (ז,ס,ב,מ,צ,ת) which were selected for good discriminability from each other and for having standard height (unlike י, ל, ק), and the distracter set consisted of the other letters of the Hebrew alphabet. For the Chinese condition, the target T1 stimuli consisted of the characters "Bu", "Xin", "Zhi", "She", Jin" and "Yin" (不,心,之,什,今,引) which were selected for having simple structure by consisting of relatively few strokes, and distracters were other Chinese characters. Importantly, T2 was from the same stimulus set (digits 1–6) under all circumstances. Due to technical limitations, the refresh rate in E3 amounted to 75 Hz rather than 100 Hz. Because of very high accuracy in pilot studies, the presentation rate in E3 was increased from 7.5 frames/s to 9.4 frames/s (107 ms per frame).

1.3. Procedure

Participants were seated in a comfortable armchair in a dimly lit laboratory room in front of the computer screen. Each trial started with the fixation cross (which was present on the screen during the entire trial), followed 800 ms later by the first letters of the streams. Subjects were instructed to maintain their gaze on the fixation cross and not to perform any eye movements during the trial. After each trial, participants were prompted to enter their response on the keyboard, first the T1 letter on the middle row of the keyboard and then the T2 digit on the number pad. A response had to be given even if the participants did not know the answer. The next trial started after the response for T2 was given. In each trial, distracter stimuli were randomly selected with replacement from the letter set. T1 and T2 were randomly selected from the target sets. Five, seven, or nine distracter pairs preceded T1 (to make precise temporal expectancies difficult; Naccache, Blandin, & Dehaene, 2002). T1 and T2 were each presented on the left or right side with equal probability. The lags between T1 and T2 amounted to 130 ms (Lag 1) or 390 ms (Lag 3, i.e., two distracter frames in-between) or 650 ms (Lag 5, four frames). In E3, Lags 1, 3, and 5 were changed to 107 ms, 320 ms and 533 ms (see above). T2 was followed by five pairs of distracters to achieve equal distance between T2 and the end of the trial. Therefore trial length varied between 12 pairs (when T1 came at the 6th position and T1–T2 lag was 1) and 20 pairs (when T1 came at 10th position and T1–T2 lag was 5). Two blocks of 360 trials each were presented. In E1, both blocks used Latin letters, whereas in E2 and E3, one block was presented with Latin letters and one with Hebrew letters (E2) or Chinese characters (E3). Block order was counter-balanced. Short practice blocks in which the frames were presented in slow motion (in E1 and E2: 500 ms instead of 130 ms of SOA; in E3: 333 ms instead of 107 ms SOA) preceded the first block in E1 and each of the two blocks in E2 and E3.

The above experimental settings resulted in three within-subjects factors: T2 Side (left or right), Side Change (T1 and T2 presented on the same or different side) and Lag between T1 and T2 (1, 3, 5), which resulted in 12 combinations that were replicated 30 times per block in random sequence.

1.4. Data analysis

Accuracy of identifying T1 and T2 was calculated separately for each of these 12 combinations, using two measures: The percentage of correct-T1 trials out of all trials (T1) and the percentage of trials when both T1 and T2 were correctly identified out of all trials in which T1 was correctly identified (T2|T1). Four-way mixed ANOVAs were computed for comparisons across E1, E2, and E3, separately for the native-language condition and for the Latin condition, with Native Language as the between-subjects factor (German, Hebrew, and Chinese) and Target Side (left/right; with target being T1 or T2, depending on analysis), Side Change (same side/different side), and Lag (1, 3, 5) as within-subjects factors. Greenhouse-Geisser correction was applied for effects of Lag. Of importance, the same Latin-letters condition from E1 was used in these two ANOVAs on native language and on Latin letters, therefore the significance threshold was lowered to $p < 0.025$ throughout.

2. Results

2.1. Comparison between participants' native-language characters

Percentages of correctly identified trials are shown in Table 1.

2.1.1. T1 identification

The results of T1 identification are presented in Fig. 2A. T1 was better identified in the right than in the left hemifield (T1 Side: $F_{1,72} = 7.1$, $p = 0.01$). Although, the interaction between Native Language and T1 Side was not significant ($F_{2,72} = 2.4$, $p = 0.1$), it is worth mentioning that this side difference did not occur in German (T1 Side in German: $F_{1,20} = 0.08$, n.s.; in Hebrew: $F_{1,27} = 9.4$, $p = 0.005$; in Chinese: $F_{1,25} = 6.4$, $p = 0.02$). Furthermore, in Chinese this right hemifield advantage was modulated by Lag and Side Change: it was absent at Lag 3 when T1 was followed by T2 on the same side and absent at Lag 1 when T1 was followed by T2 on the other side (T1 Side × Side Change × Lag: $F_{2,144} = 4.5$, $p = 0.02$; Native Language × T1 Side × Side Change × Lag:

Table 1
Percentages of correct identification of targets in the three experiments. Upper half: Identification of T2, relative to those trials where T1 was identified (T2|T1). Lower half: Identification of T1, relative to all trials. "Target Side" (entries in third row) refers to T2 side in the upper half, and to T1 side in the lower half. Values are presented as means across participants, with standard deviations in brackets.

Lag	1				3				5			
Side Change	Same		Different		Same		Different		Same		Different	
Target Side	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
T2|T1												
Exp1	94 (09)	92 (09)	74 (20)	54 (17)	84 (14)	73 (18)	86 (17)	72 (19)	88 (12)	75 (17)	89 (11)	78 (14)
Exp2 Latin	95 (04)	94 (06)	66 (24)	50 (19)	86 (13)	80 (14)	83 (21)	70 (24)	89 (10)	83 (13)	85 (17)	78 (21)
Exp2 Hebrew	97 (04)	96 (06)	70 (22)	62 (19)	88 (13)	90 (09)	84 (18)	77 (19)	92 (07)	89 (10)	91 (12)	85 (14)
Exp3 Latin	98 (03)	97 (04)	69 (17)	55 (17)	86 (10)	80 (13)	79 (14)	67 (15)	84 (11)	74 (13)	85 (10)	73 (14)
Exp3 Chinese	98 (04)	98 (04)	83 (14)	71 (20)	86 (11)	88 (11)	91 (08)	80 (20)	92 (07)	89 (09)	93 (07)	90 (09)
T1												
Exp1	86 (08)	85 (13)	85 (11)	83 (14)	87 (12)	88 (17)	89 (12)	88 (16)	89 (10)	88 (15)	89 (09)	90 (16)
Exp2 Latin	87 (10)	92 (07)	89 (10)	91 (10)	88 (11)	92 (09)	90 (09)	94 (06)	90 (10)	92 (09)	90 (10)	93 (07)
Exp2 Hebrew	84 (12)	90 (10)	86 (12)	90 (09)	87 (12)	92 (06)	89 (10)	92 (07)	89 (10)	93 (07)	90 (10)	91 (09)
Exp3 Latin	90 (08)	93 (07)	89 (10)	91 (07)	89 (07)	94 (07)	89 (07)	94 (06)	88 (09)	93 (07)	90 (06)	94 (06)
Exp3 Chinese	78 (13)	88 (08)	86 (09)	84 (09)	84 (09)	87 (07)	82 (09)	87 (07)	85 (10)	89 (07)	84 (10)	89 (07)

$F_{4,144} = 3.8$, $p = 0.006$; T1 Side × Side Change × Lag in Chinese: $F_{2,50} = 7.7$, $p = 0.002$; in Hebrew: $F_{2,54} < 0.01$, n.s.; in German: $F_{2,40} = 0.6$, n.s.; T1 Side with same-side targets in Chinese at Lag 1: $F_{1,25} = 12.7$, $p = 0.001$; at Lag 3: $F_{1,25} = 1.2$, n.s.; Lag 5: $F_{1,25} = 4.0$, $p = 0.057$; T1 Side with different-side targets at Lag 1: $F_{1,25} = 0.5$, n.s.; at Lag 3: $F_{1,25} = 5.5$, $p = 0.027$; Lag 5: $F_{1,25} = 6.9$, $p = 0.01$).

Independently of T1 Side effects, performance in T1 identification improved with longer lags (Lag: $F_{2,144} = 15.6$, $p < 0.0001$).

2.1.2. T2 identification

The results of T2 identification are presented in Fig. 2B. T2 was better identified in the left than in the right hemifield (T2 Side: $F_{1,72} = 58.4$, $p < 0.0001$) and this LVA was influenced by native language (Native Language × T2 Side: $F_{2,72} = 7.3$, $p = 0.001$) though clearly present in all three groups (T2 Side in German: $F_{1,20} = 32.5$, $p < 0.0001$; in Hebrew: $F_{1,27} = 13.5$, $p = 0.001$; in Chinese: $F_{1,25} = 8.9$, $p = 0.01$). The LVA was larger in German than in Hebrew (Native Language × T2 Side in separate analysis of E1 and E2: $F_{1,47} = 12.0$, $p = 0.001$), larger in German than in Chinese (E1 and E3: $F_{1,45} = 8.7$, $p = 0.005$) and did not differ between Hebrew and Chinese (E2 and E3: $F_{1,52} = 0.03$; n.s.).

The LVA was larger when targets were presented on different sides (T2 Side × Side Change: $F_{1,72} = 24.9$, $p < 0.0001$; T2 Side when T1 and T2 were on the same side: $F_{1,74} = 14.4$, $p < 0.0001$; when they were on different sides: $F_{1,74} = 45.9$, $p < 0.0001$). This effect was further modulated by Lag (T2 Side × Side Change × Lag: $F_{2,144} = 16.3$, $p < 0.0001$) but in different ways in the different languages (Native Language × T2 Side × Side Change × Lag: $F_{4,144} = 3.3$, $p = 0.01$; T2 Side × Side Change × Lag in German: $F_{2,40} = 13.7$, $p < 0.0001$; in Hebrew: $F_{2,54} = 1.5$, n.s.; in Chinese: $F_{2,50} = 7.7$, $p = 0.02$). In German, when T1 and T2 were presented in the same hemifield, there was no difference between left T2 and right T2 at Lag 1, but only at longer lags (T2 Side × Lag for same-side targets: $F_{2,40} = 10.8$, $p < 0.0001$; effect of T2 Side for same-side targets at each lag: Lag 1 $F_{1,20} = 0.5$, n.s.; Lag 3 $F_{1,20} = 17.3$, $p < 0.0001$; Lag 5 $F_{1,20} = 26.6$, $p < 0.0001$). The reverse effect was observed if T1 and T2 were presented in opposite hemifields (T2 Side × Lag for different-side targets: $F_{2,40} = 5.6$, $p = 0.008$). Here, the LVA was larger at the short lag and became somewhat smaller at Lags 3 and Lag 5 (Lag 1 $F_{1,20} = 33.4$, $p < 0.0001$; Lag 3 $F_{1,20} = 14.2$, $p = 0.001$; Lag 5 $F_{1,20} = 16.2$, $p = 0.001$). In Chinese, there was no LVA with same-side targets (effect of T2 Side with same-side targets $F_{1,25} = 0.4$, n.s.) and the LVA decreased across lags when targets were presented in opposite hemifields (T2 Side with different-side targets at Lag 1: $F_{1,25} = 13.1$, $p = 0.001$; Lag 3: $F_{1,25} = 7.6$, $p = 0.01$; Lag 5: $F_{1,25} = 2.5$, n.s.). In Hebrew, the LVA was not modulated by lag; like in Chinese, there was no LVA with same-side targets (effect of T2 Side with same-side targets $F_{1,27} = 2.2$, n.s.).

Apart of T2 Side effects, T2 was generally better identified among Chinese characters and Hebrew letters than among Latin letters (Native Language: $F_{2,72} = 4.5$, $p = 0.01$). The difference in T2 identification was significant between Chinese characters and Latin letters ($F_{1,45} = 9.5$, $p = 0.004$), not significant between Hebrew and Latin letters ($F_{1,47} = 2.9$, $p = 0.09$) and not significant between Chinese characters and Hebrew letters ($F_{1,52} = 1.7$, $p = 0.2$). T2 was better identified when presented on the same side as T1 than on the different side (Side Change: $F_{1,72} = 96.2$, $p < 0.0001$) and this effect dependent on Native Language (Native Language × Side Change: $F_{2,72} = 4.4$, $p < 0.02$; Native Language for same-side targets: $F_{2,72} = 7.6$, $p = 0.001$; for different-side targets: $F_{2,72} = 3.4$, $p = 0.04$; Side Change in German: $F_{1,20} = 44.7$, $p < 0.0001$; in Hebrew: $F_{1,27} = 39.1$, $p < 0.001$; in Chinese: $F_{1,25} = 32.2$, $p < 0.0001$). The difference between same-side and different-side targets was largest in Hebrew (Side Change effect in separate analysis of E2 and E3: $F_{1,52} = 6.8$, $p < 0.01$; of E2 and E1: $F_{1,47} = 3.1$, $p < 0.08$; of E1 and E3: $F_{1,45} = 1.0$, n.s.). The difference between same-side and different-side conditions disappeared at long lags, due to better performance with increasing lags (Lag: $F_{2,144} = 15.2$, $p < 0.0001$; Side Change × Lag: $F_{2,144} = 193.0$, $p < 0.0001$).

2.2. Comparison between the Latin-alphabet conditions in three nations

2.2.1. T1 identification

The results of T1 identification are presented in Fig. 3A. Overall, T1 was better identified in the right than in the left hemifield (T1 Side: $F_{1,72} = 8.1$, $p = 0.006$) and performance improved with longer lags (Lag: $F_{2,144} = 9.8$, $p < 0.0001$). Although this right hemifield advantage with Latin letters did not differ between the three nations (Native Language × T1 Side: $F_{2,72} = 2.9$, $p = 0.064$), it is worth mentioning that in case of Germans there was no right hemifield bias (T1 Side in Germans: $F_{1,20} = 0.1$, n.s.; in Israelis: $F_{1,27} = 13.0$, $p = 0.001$; in Taiwanese: $F_{1,25} = 8.8$, $p = 0.007$). No other effects were significant.

2.2.2. T2 identification

The results of T2 identification are presented in Fig. 3B. T2 was better identified in the left than in the right hemifield (T2 Side: $F_{1,72} = 83.2$, $p < 0.0001$) and this LVA was not influenced by Native Language ($F_{2,72} = 1.0$, n.s.), nor were there higher-order interactions between T2 Side and Native Language.

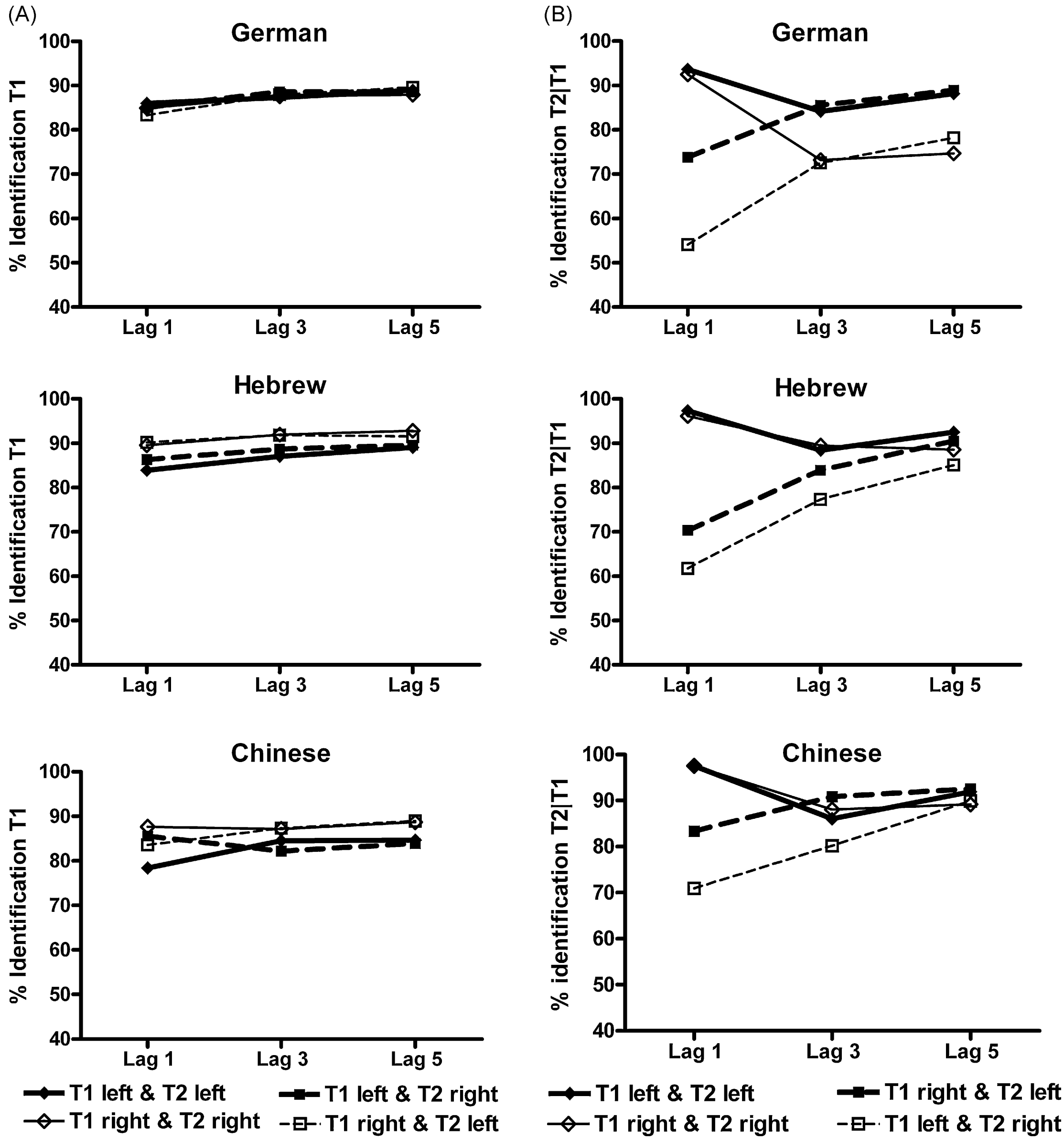

Fig. 2. Identification rates for letter-T1 (part A) and digit-T2 (part B) when T1 and distractors were characters of participants' native languages. The top panels relate to Latin letters in Germans, the middle panels to Hebrew letters in Israelis, and the bottom panels to Chinese characters in Taiwanese. T1 identification rates were calculated as the percentages of correct T1 relative to all trials. T2 identification rates were calculated as the percentages of correct T2 and T1 relative to those trials where T1 was correctly identified. Bold lines and filled symbols are for left-side targets, thin lines and empty symbols are for right-side targets. Diamonds and solid lines denote trials where sides of T1 and T2 where the same, squares and dashed lines denote trials where sides of T1 and T2 were different.

The LVA was larger when both targets were presented on different sides than on the same side (T2 Side × Side Change: $F_{1,72} = 24.2$, $p < 0.0001$) and this difference was modulated by Lag (T2 Side × Side Change × Lag: $F_{2,144} = 16.4$, $p < 0.0001$). When T2 followed T1 on the same side, the LVA was increasing with longer lags (T2 Side with same-side targets at Lag 1: $F_{1,74} = 2.0$, n.s.; at Lag 3: $F_{1,74} = 22.0$, $p < 0.0001$; at Lag 5: $F_{1,74} = 40.3$, $p < 0.0001$). When T2 followed T1 on different side, the LVA was largest at Lag 1 and decreased with longer lags (T2 Side × Lag for different-side targets: $F_{2,148} = 4.9$, $p < 0.01$; T2 Side with different-side targets at Lag 1: $F_{1,74} = 49.2$, $p < 0.0001$; at Lag 3: $F_{1,74} = 42.9$, $p < 0.0001$; at Lag 5: $F_{1,74} = 44.4$, $p < 0.0001$). T2 was better identified when T1 and T2 were presented on the same side (Side Change: $F_{1,72} = 143.4$, $p < 0.0001$) and better with longer lags (Lag: $F_{2,144} = 5.4$, $p = 0.01$). The advantage of presenting both targets at the same side decreased with longer lags (Side Change × Lag: $F_{2,144} = 304.0$, $p < 0.0001$).

The three nations differed almost significantly in the size of the Side Change effect (Native Language × Side Change: $F_{2,72} = 3.6$, $p = 0.03$; Side Change in Germans: $F_{1,20} = 44.7$, $p < 0.0001$; in Israelis: $F_{1,27} = 42.4$, $p < 0.0001$; in Taiwanese: $F_{1,25} = 113.0$, $p < 0.0001$). The difference between same-side and different-side targets was larger in Israelis and in Taiwanese than in Germans, with no difference between Israelis and Taiwanese (Side Change effect in separate analysis of E1 and E2: $F_{1,47} = 5.2$, $p = 0.027$; of E1 and E3: $F_{1,45} = 9.4$, $p = 0.004$; of E2 and E3: $F_{1,52} = 0.1$, n.s.).

3. Discussion

We tested whether the left visual-field advantage (LVA) observed in the dual-stream RSVP task can be explained as a bias induced by reading-associated preferences of directing attention to the left or right hemifield. This bias may be conceived either as

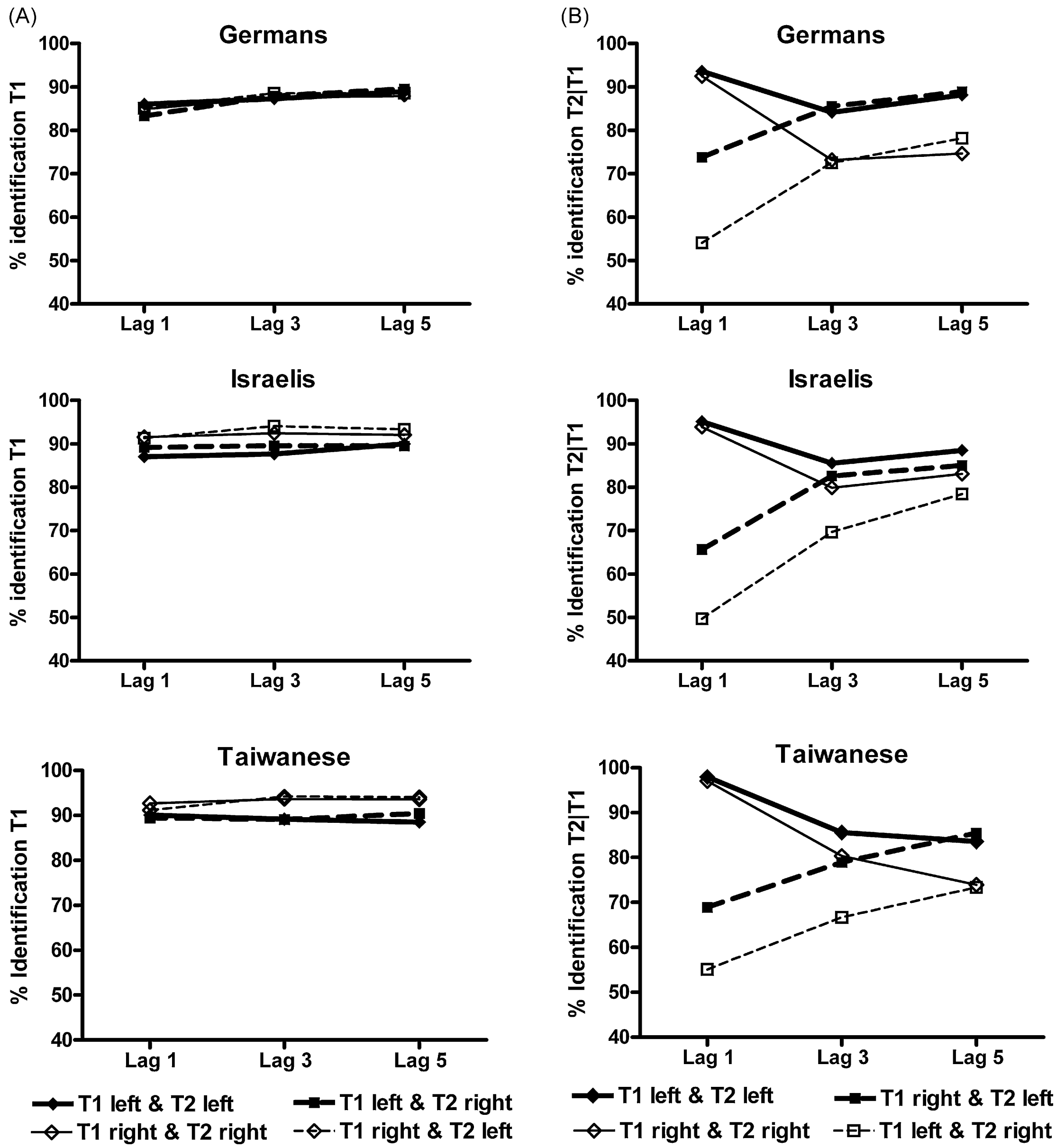

Fig. 3. Identification rates for letter-T1 (part A) and digit-T2 (part B) when T1 and distractors were Latin letters. The top panels relate to Germans, the middle panel to Israelis, and the bottom panels to Taiwanese. T1 accuracy was calculated as the percentages of correct T1 relative to all trials. T2 accuracy was calculated as the percentages of correct T2 and T1 relative to those trials where T1 was correctly identified. The meaning of the line styles and symbols is the same as in Fig. 2.

an overlearned habit applied to any kind of stimuli or as a learned response triggered by appropriate stimuli. Therefore, we compared German, Israeli, and Taiwanese participants both with the same stimuli where overlearned habits might become apparent, and with stimuli specific to their primary languages where stimulus-specific behavior would be relevant. To provide consistency across experiments, the critical T2 stimuli were always the digits 1 to 6.

3.1. Test of overlearned habits

If the LVA in native speakers of English (Holländer, Corballis, et al., 2005; Holländer, Hausmann, et al., 2005; Scalf et al., 2007) or of German (Verleger et al., 2009; Verleger et al., 2010) was due to an overlearned bias of shifting attention to the left as their starting-point of reading then the LVA should be generally reduced in native speakers of Chinese and generally reduced or even inverted in native speakers of Hebrew and Arabic not only in RSVP with letters from participant's native languages but also in RSVP with Latin letters. This prediction was strong because it is entirely opposite to hard-wired hemispheric asymmetries hypothesis. The LVA was found in both condition and, of importance, LVA did not differ between the three nations in the Latin environment in our study. This result disproved the strongest version of the reading-direction hypothesis. However, the difference between T1–T2 presented in the same side and in the opposite sides smaller in Germans than in Israelis & Taiwanese might speak in favor of slight influence of habitual reading-direction on the LVA. This difference might be explained by more difficult reengagement of attention to the right hemifield after right T1 in German than in Israelis and Taiwanese due to their habitual preference to refocus attention rather to the left side.

The equal LVA in Latin conditions in the three nations may appear to be in conflict with results quoted in the Introduction where culture-specific biases according to reading habits were obtained, e.g. in the line-bisection task by Chokron and Imbert (1993), Chokron and De Agostini (1995), Chokron et al. (1997)

and Zivotofsky (2004). Viewed under the hypothesis of stimulus-induced lateral bias, it may be argued that Latin letters induce a general bias in any participant who is familiar with Latin letters irrespective of the use of these letters as primary or secondary script, whereas the script-independent lines presented in the bisection task provide a more neutral frame for bringing out writing-associated habits that differ between cultures. Viewed under the hard-wired asymmetry hypothesis, the dual-stream RSVP task might be more suitable to bring out the LVA, by pushing the attentional system to its limits, than the undemanding line-bisection task which therefore leaves degrees of freedom to be filled with learned habits.

3.2. Test of stimulus-induced bias

If the LVA in a Latin-letter environment was due to overlearned responses to these letters in shifting attention to the left as the starting-point of reading then the LVA should be inverted, to become an RVA, in native speakers of Hebrew and Arabic and should be largely absent in native speakers of Chinese, but should be present in RSVP with Latin letters even if performed by Israelis and Taiwanese. We obtained a reliable LVA in each language. The presence of the LVA in dual RSVP with Hebrew and Chinese characters supports the notion that it does not reflect a culturally learned bias but rather some general principle of brain organization. At the same time, evidence was obtained that stimulus-induced biases do exist, modifying the general LVA: though present, the LVA was reduced in Hebrew- and Chinese-speaking participants. It follows that the LVA that has been reliably obtained in native speakers of English and German in this and previous studies somewhat overestimates the general, "hard-wired" asymmetry, by further adding a left-side bias specific to the use of Latin letters. But the general presence of the LVA in the present data, against any stimulus-induced tendencies, confirms the existence of a culture-independent component of the LVA. This conclusion gets support by results of a previous study (Holländer et al., 2005b) where presence of a culture-independent component could be inferred from variation of the LVA rather than from its stability. In that study, the LVA was systematically modulated by the menstrual cycle in women, in line with the known general variation of hemispheric functional asymmetry during the menstrual cycle (Hausmann & Güntürkün, 2000).

We had expected to obtain additional information about the mechanisms contributing to the LVA by the time-course of their effects on the LVA. Indeed, the LVA varied across lags between T1 and T2 in different ways with the different languages. When T1 and T2 were on the same side, an LVA was obtained at lags 3 and 5 with Latin characters only, not in the Hebrew and Chinese conditions. (Performance was almost perfect at lag 1 in all languages, reflecting lag-1 sparing, cf. Olivers & Meeter, 2008). It appeared as if it was the most difficult to keep attention focused on the right side with Latin letters when already T1 had been on that side. So it may be presumed that this is the instance where stimulus-specific factors promoting the LVA have most impact, promoting a tendency to shift attention back to the starting-point of reading on the left side. Less obvious is the interpretation of the differential effect when T1 and T2 were on different sides. In this case, the LVA did not decrease across lags in the Hebrew condition, slightly decreased in the Latin condition and totally disappeared at lag 5 in the Chinese condition.

At least one other explanation of the difference in the size of the LVA between Latin vs. Hebrew and Chinese conditions is possible, alternatively to postulating stimulus-induced reading reflexes. The smaller LVA with Hebrew and Chinese characters might be due to better discriminability of digits among this stimulus material. It has been shown that the LVA manifests itself to a smaller extent when targets and distracters are less similar to each other (Hellige, 1983; Hellige & Webster, 1979; Scalf et al., 2007). This interpretation is probable through the fact that T2 was generally better identified when embedded between Hebrew and Chinese characters than Latin letters. These issues might be further clarified by future experiments that would manipulate identification difficulty of T1 and T2. In any case, as noted, both presumed mechanisms leave the constant presence of the LVA unexplained which, therefore, appears to be due to general features of hemispheric functioning. In the remainder of this paper, we will discuss possible mechanisms underlying this general LVA.

3.3. Possible mechanisms of the LVA in the dual-stream RSVP task

Our results provide support for the notion that the left visual-field advantage for T2 in dual RSVP might reflect some general asymmetries between hemispheres in visual processing. However, it is not clear so far what the underlying mechanisms are.

When interpreting the LVA in dual RSVP as due to right-hemisphere superiority, possible mechanisms might be related to dominance of the right-hemisphere in control of spatial attention. Brain structures mediating shifts of attention are mainly active in the right-hemisphere (Corbetta, Miezin, Shulman, & Petersen, 1993; Nobre et al., 1997). It has been proposed that the right-hemisphere directs attention to both hemifields, whereas the left hemisphere is able to direct attention only to the contralateral hemifield (Mangun et al., 1994; Mesulam, 1981, 1990). An alternative model states that representations of the left hemifield in the brain are stronger than representations of the right hemifield (Siman-Tov et al., 2007). According to both proposals, attention might be constantly biased toward the left side of the visual field. Moreover, if shifts of attention are mediated by the right-hemisphere, then any shift of attention will activate the right-hemisphere, thereby further alleviating the processing of a left T2 in comparison to a right T2 when T1 and T2 are presented at different locations. The superiority of the right-hemisphere might also result from better perceptual rather than attentional processing. As pointed out by Hellige and Webster (1979), the right-hemisphere might outperform the left one in extracting complex visuospatial information from visual displays, particularly when stimuli are degraded. Accordingly, even for verbal stimuli (cf. further below), initial stages of information processing must involve the extraction of relevant visual features and spatial relations among those features (see also Hellige, 1990). Therefore masked letters are better processed in the left than in the right visual hemifield (Hellige, 1983; Hellige & Webster, 1979).

According to Kinsbourne (1993), the hemispheres must compete for activation and coordinate their performance by exerting mutual inhibition on each other. Thus, the present LVA might result from the inhibitory influence exerted by the right-hemisphere over the left one. There might be several causes for the larger activation of the right-hemisphere. One might be related to the above-mentioned greater involvement of the right-hemisphere in spatial attention. Another might be related to a greater role played by the right-hemisphere in arousal and sustained attention (Heilman & Van Den Abell, 1979; Pardo, Fox, & Raichle, 1991; Sturm, Reul, & Willmes, 1989; Whitehead, 1991). Accordingly, the rapid presentation of stimuli in our task might lead to greater activation of the right-hemisphere, thereby to inhibition of the left hemisphere and, due to either process, to better identification of targets in the left visual field, possibly by limiting the access to working memory for items processed by the left hemisphere (Scalf et al., 2007).

The LVA in our dual RSVP task might alternatively result from impaired processing of T2 in the left hemisphere rather than from the dominance of the right one. Somewhat counterintuitively at first sight, this might be true not although but rather because the left hemisphere is specialized in processing verbal stimuli (Gazzaniga, 2000), in particular, in identifying briefly flashed verbal information (Gazzaniga, 1995; Hausmann & Güntürkün, 2000). Namely, processing of letters (T1) by the left hemisphere might disrupt further processing of T2 in the same hemisphere due to its overload (see also for the same suggestion Holländer, Corballis, et al., 2005, and for a similar notion Hellige et al., 1979). This would explain why right T2 presented after right T1 is processed less effectively than left T2. Furthermore, because of obligatory processing of T1 by the left hemisphere, processing of T2 after right T1 would be less postponed compared to the situation when the right-hemisphere receives T1 and has to transmit this information to the left hemisphere. This would explain why the combination of right T1 and left T2 is processed more effectively than left T1 and right T2. Although attractive, this hypothesis fails to explain why this difference between hemispheres does not already emerge in processing T1. Although in the case of Israelis and Taiwanese T1 was indeed better identified in the right than in the left hemifield, this pattern of results was not observed in Germans, nor in previous experiments with this task (Holländer, Corballis, et al., 2005; Holländer, Hausmann, et al., 2005; Scalf et al., 2007; Verleger et al., 2009; Verleger et al., 2010).

Similarly, it might be assumed that it is the often-reported superiority of the left hemisphere in temporal processing (Elias, Bulma-Fleming, & McManus, 1999; Nicholls, 1994, 1996; Nicholls & Atkinson, 1993; Okubo & Nicholls, 2008) that might render it more susceptible to irrelevant information provided by the distracters. However, it has been argued that susceptibility to irrelevant information, for example in case of the attentional blink, is caused by slower rather than faster temporal characteristics of the attentional system. According to the Boost and Bounce theory of temporal attention (Olivers & Meeter, 2008), distractors influence the processing of targets because the attentional system works too slowly and is not able to “close” the “attentional window” before the distractors arrive. From this point of view, the left hemisphere, if indeed better in temporal processing, should suffer from distractors to a smaller extent, which is not the case. Second, it has been suggested that it is the right-hemisphere that is better in temporal processing of relevant information because it might single out events in time faster (Hellige & Webster, 1979). Indeed, some neurophysiological evidence in favor of this view has been provided in the RSVP task, by Kessler et al. (2005) who obtained two distinct peaks of the P3 component in their MEG measurements only at the right-hemisphere when T1 and T2 immediately followed each other, and by our preceding study (Verleger et al., 2009) where the *N2pc* component contralateral to the side of either T1 or T2 reached its peak earlier at the right-hemisphere (when evoked by left hemifield targets) than at the left hemisphere (when evoked by right hemifield targets). Possibly in line with this evidence, larger relevance of the right-hemisphere for temporal processing was found in patients with brain lesions (Harrington, Haaland, & Knight, 1998) and in fMRI studies (Rao, Mayer, & Harrington, 2001). Indeed, the two hemispheres may make differential contributions to temporal processing depending of the nature of the task (Funnell, Corballis, & Gazzaniga, 2003; Okubo & Nicholls, 2008). The left-hemisphere probably outperforms the right one in transient detection, namely when rapid or transient temporal change in a visual scene have to be detected. The right-hemisphere outperforms the left one in sustained monitoring of temporal changes (Okubo & Nicholls, 2008).

Finally, because of the complexity of the dual RSVP task, it seems quite probable that the LVA resulted from the interaction of two or more of the mentioned factors. For example, the larger LVA when T1 and T2 are presented in different hemifields than when presented in the same hemifield might be a combined effect of larger control over spatial attention in the right-hemisphere and of right-hemispheric specialization in aspects of temporal attention: when T1 and T2 are presented in the same hemifield only the temporal characteristics might have played a role. In any case, studies on cerebral asymmetries in the dual RSVP task might contribute to better understanding of the organization of attentional systems because of its requiring both spatial and temporal attention, which might be relevant for full understanding of pathological conditions as well (Husain, Shapiro, Martin, & Kennard, 1997).

4. Conclusion

In conclusion, hemifield differences in identifying digits in rapidly presented streams were affected by the nature of the characters displayed in these streams: Hebrew vs. Latin and Chinese vs. Latin. These effects can plausibly be interpreted as differences in directing attention that are associatively linked to each of these two alphabets. Nevertheless, a general left visual-field advantage in T2 identification remained in all groups of participants, rather than being replaced by a right visual-field advantage with Hebrew letters and no differences between hemifields with Chinese characters. Therefore, it appears justified to maintain an interpretation of the left visual-field advantage in dual RSVP as reflecting some general mechanism of the organization of attentional processes between the two hemispheres.

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