The role of frontoparietal circuit in time discrimination: a rTMS study

Poster No:

293 MT-AM

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Introduction:

The ability to accurately perceive time is crucial for most of cognitive processes, such as for the efficient organization of sequences of actions, or in predicting and anticipating coming events. The mechanisms by which the brain measures time, however, are still an open issue. Functional brain imaging studies have suggested the involvement of multiple interconnected brain areas in the processing of time. A frontoparietal cortical network has been consistently reported to intervene in processing durations longer than 1 sec (Lewis and Miall, 2006), including the right dorsolateral prefrontal cortex, the supplementary motor area, and the inferior , and the inferior parietal cortex (Koch et al., 2009; Coull et al., 2008; Macar et al., 2006; Buhusi and Meck, 2005; Smith et al., 2003; Rao et al., 2001). The present study was aimed at identifying the specific contribution of different cortical areas within this network in a temporal discrimination task by means of repetitive TMS technique.

Methods:

Ten University students (21-25 years) completed a time discrimination task. The task consisted of two successively presented pairs of visual stimuli. The stimuli were always the same grey image presented at the center of the screen on a black background. The first stimulus (standard interval) lasted either 500 or 1500 ms; the second stimulus (comparison interval) could have duration 20 or 30%, shorter or longer than the standard one. Participants were asked to compare the duration of the two stimuli and to determine whether the comparison interval was shorter or longer than the standard interval.
The experiment was divided in four sessions, two for each standard duration, and each participant was tested in four different days. Within each session, three experimental blocks were administered, originated from the combination of six cortical sites and two temporal windows. Trains of three TMS pulses were delivered at 10 Hz at the onset, or 80 ms after the offset, of the comparison interval. The stimulated site was one of the following: right and left supplementary motor area (SMA), right and left angular gyrus (AG), right dorsolateral prefrontal cortex (DLPFC), and control site. Brainsight stereotaxic system was used to localize these cerebral areas and to control coil position throughout the sessions.
The coefficient of variation (CV) and the percentage of "shorter" responses were analyzed considering the absolute duration (500 vs. 1500 ms ranges), the relative duration of the comparison interval (shorter vs. longer), and the stimulated sites as within-subject factors. TMS data were also compared with results of a behavioral study, in which the same experimental sessions were administered without TMS.

Results:

Data showed that mean coefficients of variation were significantly influenced by the site and the time of stimulation. In the study without TMS, we found that CV values were higher 1) in trials requiring the discrimination of intervals longer than the standard in the 500 ms range, and 2) in trials requiring the discrimination of intervals shorter than the standard in the range of 1500 ms. In the TMS study, when the rSMA was stimulated at the onset of the comparison duration the previously described effect was completely reversed ($F(1,9)= 14.98$, $p= .018$, $\eta 2p = .79$). Furthermore, the stimulation of the rAG lead to a disappearance of any interaction between absolute and relative duration.
When the percentage of "short" responses was examined, a constant tendency to underestimate intervals in the 500 ms range and to overestimate intervals in the 1500 ms range was found in the study without TMS. This tendency was reversed by rTMS applied over frontal sites. In particular, the magnetical stimulation over the rDLPFC at the onset of the comparison interval produced an overestimation of interval in the 500 ms range (main effect of standard duration F

(1,9)= 5.14, p= .04, $\eta 2p$ = .72). More interestingly, the tendency observed in underestimating intervals below 1 sec and in overestimating intervals above 1 sec did not emerge when the rAG was stimulated at the offset of the comparison interval.

Conclusions:

Results suggest that absolute and relative durations are processed by different cortical areas within the frontoparietal network, which intervene in different time windows. The rSMA was presumably engaged in processing the absolute duration at an encoding level. The rDLPFC involvement in discriminating intervals shorter than 1 sec supports the idea that a in an explicit timing task also very brief durations imply high cognitive resources. The rAG seems to intervene both at the onset and at the offset of the interval to be discriminated and might probably be responsible of quantification processes.
These findings are in accordance with the fact that although time may be considered as a linear function, how the brain builds a representation of the passage of time is a much more complex phenomenon.

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