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Fast Object Perception in The Subcortical Pathway: a Commentary on Wang *et al.*'s Paper in *Human Brain Mapping* (2023)*

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Abstract The subcortical visual pathway is generally thought to be involved in dangerous information processing, such as fear processing and defensive behavior. A recent study, published in *Human Brain Mapping*, shows a new function of the subcortical pathway involved in the fast processing of non-emotional object perception. Rapid object processing is a critical function of visual system. Topological perception theory proposes that the initial perception of objects begins with the extraction of topological property (TP). However, the mechanism of rapid TP processing remains unclear. The researchers investigated the subcortical mechanism of TP processing with transcranial magnetic stimulation (TMS). They find that a subcortical magnocellular pathway is responsible for the early processing of TP, and this subcortical processing of TP accelerates object recognition. Based on their findings, we propose a novel training approach called subcortical magnocellular pathway training (SMPT), aimed at improving the efficiency of the subcortical M pathway to restore visual and attentional functions in disorders associated with subcortical pathway dysfunction.

Key words transcranial magnetic stimulation (TMS), subcortical pathway, magnocellular pathway, topological property, object perception

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How does the visual system quickly perceive the presence of an object before we can identify it in detail topological perception theory[1-2] is proposed to address the question of how objects are perceived in the early stages of vision, which holds that the visual system first extracts the topological property (TP) of objects to build up object representation. The TP of an object is a geometric property based on mathematical topology. The TP remains the same during any continuous deformations such as stretching and bending but changes when tearing. Substantial behavioral evidence[1-6] shows that the processing of TP has priority over that of other properties. However, a seemingly paradoxical finding from previous functional magnetic resonance imaging (fMRI) studies[7-8] is that TP perception occurs primarily in the inferior temporal cortex (IT), which is the end of the classical visual pathway. A subcortical pathway hypothesis for TP processing is proposed that TP processing projects directly from the retina to the fast superior colliculus (SC)-pulvinar-amygdala subcortical pathway and finally to the cortical IT. This hypothesis has been supported by some evidence from humans and mice[9-10] (Figure 1). Specifically, a human fMRI study[9] found that the processing of "hole", as a TP, activated the SC and pulvinar more in response to unconscious stimuli than conscious stimuli. In addition, the researchers sought evidence of subcortical neurons in mice[10]. They presented the

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mice with a looming stimulus that mimicked a dangerous predator from the sky. And they found that when the TP of the looming stimulus changed, the instinctive fear response of mice was significantly reduced, as was the number of neurons activated in the SC. This suggests that the rapid processing of fear signals in subcortical pathways may be related to TP processing. However, these studies did not rule out the effect of cortical processing, so the observed subcortical activation may come from cortical to subcortical feedback signals.

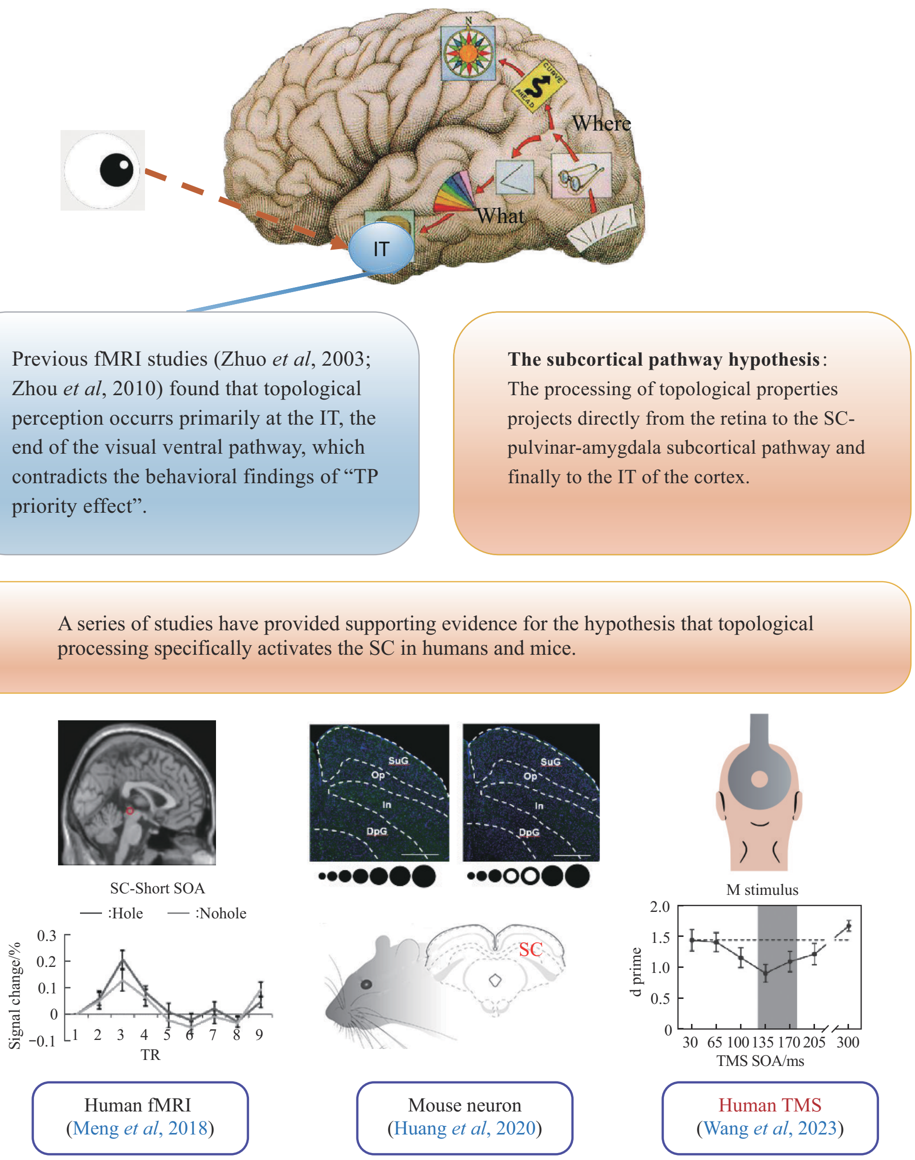

Fig. 1　The subcortical pathway hypothesis and its supporting evidence

Superior colliculus (SC) plays a key role in visual information integration, eye movement control and spatial attention. fMRI: functional magnetic resonance imaging; IT: inferior temporal cortex; TP: topological property; TMS: transcranial magnetic stimulation; SOA: stimulus onset asynchrony.

Recent work in *Human Brain Mapping* by Dr. Huang's group[11], titled "A subcortical magnocellular pathway is responsible for the fast processing of topological properties of objects: a transcranial magnetic stimulation study", rules out this possibility. Using transcranial magnetic stimulation (TMS) to block the primary visual cortex at different times, the researchers found that topological processing is processed independently of the classical visual cortical pathway in the early stages, but *via* a subcortical pathway. Moreover, according to the processing characteristics of magnocellular (M) and parvocellular (P) cells, the researchers designed an M stimulus (low-contrast grayscale image) that favored the M-pathway processing and a P stimulus (isoluminant red/green image) that favored the P-pathway processing. They used this M/P pathway separation technique to find that the rapid perception of TP is through the subcortical M pathway. Furthermore, they demonstrated the significance of rapid subcortical processing of TP to facilitate the recognition of other properties of objects.

The finding of the subcortical M pathway involved in rapid object processing extends our traditional understanding of M and P pathways. First, structurally, the M and P pathways are generally thought to correspond to the dorsal and ventral cortical pathways, respectively[12]. This finding extends the M pathway from the cortex to the subcortex. Second, functionally, the M pathway in the dorsal cortex is responsible for processing information like depth and motion[13], while the subcortical M pathway was found to be responsible for the rapid processing of objects' TP, suggesting a functional separation of the cortical and subcortical M pathways, even though both exhibit sensitivity to low contrast.

This study is an important step forward in exploring the function of human subcortical visual pathways. Subcortical visual pathways are generally considered to be involved in important survival-related information, such as fear processing and defensive behavior. This study provides support for the key role of the subcortical pathway in rapid object recognition, extending the previous understanding of subcortical pathways. Abnormalities in subcortical pathways has been reported in many brain diseases, such as schizophrenia, glaucoma, and anxiety disorders. Early schizophrenia is thought to be accompanied by abnormal functioning of the subcortical (SC-pulvinar-amygdala) pathway[14]. Glaucoma, often considered as an ocular disease, has also been found to have abnormal subcortical SC function in its early phases[15]. Additionally, anxiety disorders have been linked to altered functioning of the subcortical pathway, with stress-induced changes in the locus coeruleus (LC) and SC further exacerbating anxiety symptoms[16]. This study will help the understanding of the pathogenesis of related brain diseases from a new perspective of the subcortical pathway and provide new research ideas for early screening, objective diagnosis, and intervention strategies.

Based on the findings of Wang *et al.*[11], we put forward a novel subcortical magnocellular pathway training (SMPT) as an early prevention and intervention strategy for related diseases.

This cognitive training is designed to enhance the function of the subcortical magnocellular pathway *via* visual TP processing training, particularly unconscious topological processing. Based on the previous research paradigms of visual topological properties[3-5, 10], we aim to effectively train the subcortical M pathway to restore its normal function through the combination of visual masking, looming, the unconscious priming paradigm, and peripheral visual field presentation. As shown in Figure 2, participants will undergo a 4-week training program, consisting of 2 sessions per week for a total of 8 sessions, with each session lasting approximately 20−30 min. The expected effects of SMPT include enhanced visual attention, faster information processing, and improved perceptual-cognitive integration through the activation of the M pathway. It may also facilitate emotional regulation, particularly in individuals with emotion-perception dysfunctions. However, the limitations of SMPT should also be acknowledged. Given that SMPT primarily targets subcortical structures through the activation of the magnocellular pathway, its therapeutic effects may be most applicable to conditions involving early-stage or subcortical dysfunctions, and its applicability has yet to be systematically validated. In addition to cognitive training, subcortical interventions can be enhanced through neuromodulation techniques such as deep transcranial magnetic stimulation (dTMS) and temporally interfering electrical stimulation (TIES). These approaches allow for more direct targeting of deep brain regions, potentially increasing the efficiency and precision of the intervention. Integrating stimulation with training tasks may lead to more robust and long-lasting neuroplastic changes, offering promising avenues for clinical application.

The M pathway mainly processes dynamic and blurry information, such as motion and spatial changes, with fast response but low precision, making it suitable for quickly perceiving environmental changes. The P pathway, on the other hand, focuses on details and color information, excelling at processing high-precision, static images to help recognize object shapes and colors. The subcortical pathway shares

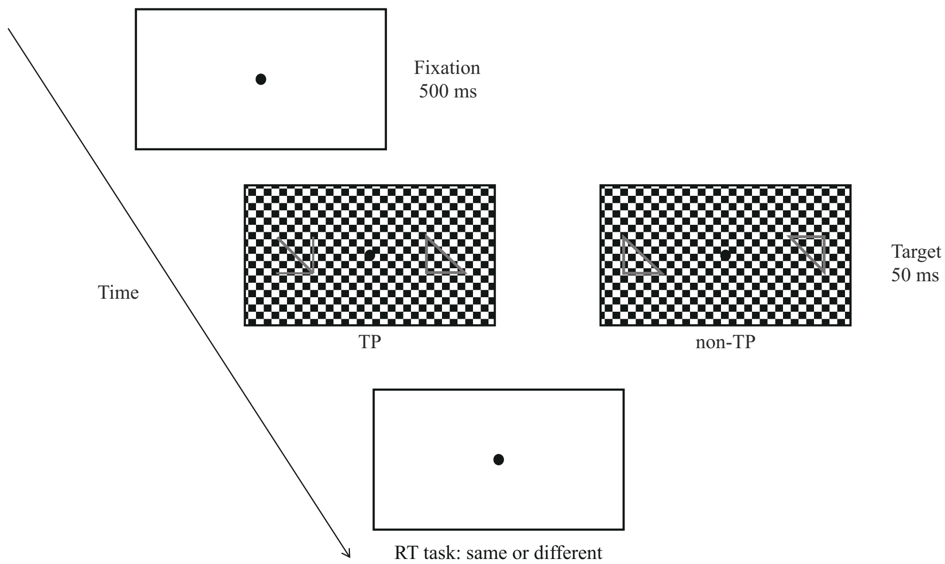

Fig. 2 SMPT design: topological stimuli for M pathway activation

TP: topological property; RT: reaction time.

characteristics with the M magnocellular pathway, processing fast, low-precision information, and plays a crucial role in threat detection and instinctive responses. Due to its highly automated and unconscious nature, this pathway is difficult to directly modulate through conventional visual tasks. However, SMPT can activate and optimize this pathway through targeted training, showing potential for anxiety regulation and reshaping threat sensitivity. It can particularly benefit from combining rapid topological recognition tasks to enhance the role of the magnocellular pathway in emotional regulation.

Future studies could further clarify which subcortical nuclei and subregions are involved in rapid TP processing, and it is also worthwhile to use animals to investigate the neural circuit mechanism of the visual system preferentially processing TP.

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皮层下通路中的快速物体识别：对Wang等在 *Human Brain Mapping*发表文章（2023）的评论*

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摘要 皮层下视觉通路通常被认为与危险信息处理有关，比如恐惧处理和防御行为。最近发表于*Human Brain Mapping*杂志的一项研究表明，皮层下通路具有一种新功能，能够快速加工一般性（非情绪相关）物体的拓扑性质。快速加工物体是视觉系统的一项重要功能。拓扑知觉理论指出，物体的初始感知觉起始于拓扑性质的提取。然而，拓扑性质快速加工的机制尚不明确。研究人员通过经颅磁刺激（TMS）研究了脑皮层下拓扑性质加工的机制。他们发现，皮层下的大细胞通路负责拓扑性质的早期加工，而且这种皮层下的拓扑加工加快了对物体的识别。基于他们的发现，本文提出了一种新的训练方法，称作皮层下大细胞通路训练（SMPT），旨在提升皮层下M通路的效率，以恢复与皮层下通路功能障碍相关的脑疾病患者的视觉和注意功能。

关键词 经颅磁刺激，皮层下通路，大细胞通路，拓扑属性，物体识别

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