心理与行为科学研究中心 2017-2019 重要成果汇编

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导 论

持续关注弱势群体 补齐全面小康短板

——兼谈"项目缘起"与"团队学术关注"

习近平新时代中国特色社会主义思想的战略路径选择之一就是"精准扶贫"。 因此,"贫困"这一关键词极其自然地进入各级党委和政府领导者以及理论界学者 的视野。那么,"贫困"如何进行定义呢?古人有两种释义:一是指"贫苦困厄", 即缺少财物、困顿不顺。如《荀子·性恶》有云:"仁之所在无贫穷,仁之所亡无 富贵";再如,《战国策·秦策一》有载:"苏秦曰:'嗟乎!贫穷则父母不子,富贵 则亲戚畏惧。人生世上,势位富贵,盖可忽乎哉!'"二是指"穷人"。如《礼记· 月令》有载:"天子布德行惠,命有司发仓廪,赐贫穷,振乏绝。"而在现实生活 中,言及"贫困",人们总是习惯地从区域的视角来进行审视,并极其自然地将 "贫困"与"老、少、边、远"地区联系起来,即革命老区、少数民族地区、边疆 地区等经济落后区域。如果我们将研究视野转向"人群",即"贫困人群",那么, 我们就不难发现,"贫困"现象就不仅仅是"老、少、边、远"地区的代名词了。 尽管"老、少、边、远"地区的"贫困"现象分布相对集中,甚至是普遍现象,但 是,只要稍加留意和粗略浏览,即便在经济发达地区和沿海一线城市,"贫困"现 象也并不鲜见,这就是"弱势群体"。

如果说,"精准扶贫"是一项国家战略,那么,在有效实施和推进这项国家战略时,其聚焦关注、路径选择等行为表达,就不能仅仅关注"区域",更应该关注 "人群"。因为组织的功能往往取决于其结构,尤其是组织的"短板"。这就如同最近美国对中国发起的贸易战,作为世界唯一的超级大国,美国绝对不会容忍中国的 崛起,它必然选择严重制约中国科技产业和现代加工制造业迅猛发展的核心技术 (如芯片)下手,阻滞甚至阻止诸如"2025中国制造"等现代化进程。如果说,科 学技术创新是制约中华民族伟大复兴进程的"瓶颈"问题,那么,从社会发展角度 看,关注"弱势群体"、有效精准扶贫也是亟待解决、并且必须持续关注的难题。

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论

持续关注弱势群体 补齐全面小康短板



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陆道平 / 著

200718853

城乡公共服务均等化 与基层政府职能建设

THE EQUALIZATION OF URBAN AND RURAL PUBLIC SERVICES AND THE BUILDING OF LOCAL GOVERNMENT FUNCTIONS



2017022853



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推进公共服务均等化、让城乡居民共享发展成果是全 面实现小康社会的重要内容。而基层政府作为中央政府和 上级政府公共服务政策的最终落实者,直接面对城乡民众, 对公共服务的诉求也有直观的了解,因而要真正实现城乡 公共服务的均等化、推动共享式发展,需要地方政府尤其 是基层政府实现理念和职能的有效转型。

本书基于城乡一体化的理论,从价值导向、供给能力 和需求主体的三维角度,建构了城乡一体化进程中基层政 府公共服务的理论模型,将基层政府公共服务的供给模式 创新性地划分为三类,即"双向应对型""后发赶超型""内 生综合型",并以江苏苏南、苏中和苏北地区经济社会发 展水平不等的三个乡镇(街道)作为研究对象,通过实地 访谈和问卷调查的方式,对三种模型进行了较为详尽系统 的分析和比较。并在综合考察相关地区基层政府均等化服 务模式的现实形态基础上,借鉴西方发达国家公共服务的 相关经验,提出要着力推动城乡一体化中基层政府服务均 等化,其动力基础应从外部压力型向内部需求型转变,观 念体系要从补助导向朝权利导向转变,制度平台则要从粗 疏应对向精细管理转变,运行机制要从"一元"向"多元" 转变,逐步实现基层公共服务"内生综合型"模式的形成。



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初级视觉皮层在注意振荡中的作用*

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摘 要 注意离散性是注意间歇性地采集外界信息的特性,这种特性在行为中的表现被称为注意振荡。尽管有研究使用经典的线索靶子范式和视觉搜索范式发现行为数据中存在注意振荡,证明了注意是离散的,但其相应的神经机制,即注意离散性与哪些脑区有关,尚不明确。研究采用高时间分辨率的线索靶子范式和双眼分视技术,基于人眼视觉通路的解剖学特性,比较了线索靶子出现在双眼(实验1)、同眼和异眼(实验2)条件下的注意振荡,考察初级视觉皮层对注意振荡的影响。结果发现:1)双眼分视会对注意振荡发生的频段产生影响,非双眼分视条件下,注 意振荡出现在低频(2 Hz 和 8 Hz)。而双眼分视条件下,注意振荡则出现在更高的频段(12.5 Hz)。2)无论线索靶子出现在同眼还是异眼,注意振荡的频段无显著差异。结果表明 V1 区双眼视觉通路或者更高级的视觉区可能参与注意振荡,为探明注意振荡的神经机制提供了重要的行为学证据。

关键词 注意振荡;初级视觉皮层;双眼分视;高时间分辨率;线索靶子范式 分类号 B842

1 引言

一个朋友从远处走来时,我们看到他自然地经 过了沿途的每一个位置,所以主观意识上觉得注意 在时间维度上似乎也是连续的。但实际上,这种意 识的连续性并不能证明注意的连续性。注意可能每 隔几十毫秒采集一次信息,然后构建整体的知觉, 同时又保证意识状态的连续性(VanRullen & Koch, 2003)。近期,诸多研究表明,注意并非连续地而是 间歇性地加工外界信息(Busch & VanRullen, 2010; Landau & Fries, 2012; Song, Meng, Chen, Zhou, & Luo, 2014; VanRullen, Carlson, & Cavanagh, 2007)。注意 的这种特性被称为"注意的离散性",指在精细的时 间尺度上,注意间歇性地采集外界信息的特性,即 "采集"、"停止"、"采集"、"停止"……如此循环往 复(VanRullen et al., 2007)。该特性在行为上表现为 指标(正确率或反应时)有规律地时高时低,这种由 于注意导致的行为指标有规律的变化被称为注意 振荡(attention oscillation)。新近研究采用高时间分 辨率的行为学研究方法,打破了传统认知任务不能 精细研究注意离散性的局限,直接在被试的行为中 (探测正确率和反应时)发现了振荡模式(Benedetto, Spinelli, & Morrone, 2016; Chen, Wang, Wang, Tang, & Zhang, 2017; Dugué, Marque, & VanRullen, 2015; Dugué, McLelland, Lajous, & VanRullen, 2015; Dugué, Roberts, & Carrasco, 2016; Fiebelkorn, Saalmann, & Kastner, 2013; Huang, Chen, & Luo, 2015; Landau & Fries, 2012; Song et al., 2014)。

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The primary visual cortex modulates attention oscillation

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Abstract

It has been well documented that the spotlight of attention is intrinsically rhythmic, which discretely samples a single or multiple objects. Adopting high resolution behavioral approach, attention oscillation has been revealed. However, neural mechanism of attention oscillation remains poorly understood. In the present study, basing on functional anatomy of the primary visual cortex, we aimed to investigate the role of primary visual cortex (V1) in attention oscillation, by using a modified high temporal resolution cue-target paradigm in a 4AFC task.

In the present study, behavioral oscillations in visual attention under ordinary (binocular; not dichoptic) viewing condition (exp. 1) and binocular dichoptic (exp. 2) condition were examined. In experiment 1, 16 paid participants were asked to detect target at either the previously cued (valid condition) or uncued location (invalid condition). The cue-target SOA varied from 0.1 s to 1.08 s in steps of 20 ms. Performances were evaluated in a 4AFC task. If they saw target, they were instructed to judge the location of the target (1 for target on the upper left; 2 for upper right; 4 for lower left; 5 for lower right) on the keypad. While, 16 paid participants were recruited to detect target at either cued or uncued locations under binocular dichoptic condition. Target could occur in the same or different eye of cue stimuli. Amplitude of target contrast decrement was determined with QUEST procedure before cue-target experiment. Except that no cue stimuli were presented, threshold procedure was identical to the cue-target experiment procedure.

Results showed that when grating locations were presented under ordinary viewing condition, a theta rhythm was visible. While targets were presented in the same or different eye under binocular dichoptic condition, attention oscillation was clearly seen at 12.5 Hz with antiphase relationship between cued and uncued conditions.

The findings under ordinary viewing condition are in general consistent with previous studies. While, under binocular dichoptic condition, attention oscillation increased to a higher frequency. This study indicates that attention oscillation may occur at or beyond primary visual cortex where binocular integration begins.

Key words attention oscillation; V1; binocular dichoptic; high temporal resolution; cue-target paradigm

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初级视觉皮层在注意振荡中的作用*

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摘 要 注意离散性是注意间歇性地采集外界信息的特性,这种特性在行为中的表现被称为注意振荡。尽管有研究使用经典的线索靶子范式和视觉搜索范式发现行为数据中存在注意振荡,证明了注意是离散的,但其相应的神经机制,即注意离散性与哪些脑区有关,尚不明确。研究采用高时间分辨率的线索靶子范式和双眼分视技术,基于人眼视觉通路的解剖学特性,比较了线索靶子出现在双眼(实验 1)、同眼和异眼(实验 2)条件下的注意振荡,考察初级视觉皮层对注意振荡的影响。结果发现:1)双眼分视会对注意振荡发生的频段产生影响,非双眼分视条件下,注 意振荡出现在低频(2 Hz 和 8 Hz)。而双眼分视条件下,注意振荡则出现在更高的频段(12.5 Hz)。2)无论线索靶子出现在同眼还是异眼,注意振荡的频段无显著差异。结果表明 V1 区双眼视觉通路或者更高级的视觉区可能参与注意振荡,为探明注意振荡的神经机制提供了重要的行为学证据。

关键词 注意振荡;初级视觉皮层;双眼分视;高时间分辨率;线索靶子范式 分类号 B842

1 引言

一个朋友从远处走来时,我们看到他自然地经 过了沿途的每一个位置,所以主观意识上觉得注意 在时间维度上似乎也是连续的。但实际上,这种意 识的连续性并不能证明注意的连续性。注意可能每 隔几十毫秒采集一次信息,然后构建整体的知觉, 同时又保证意识状态的连续性(VanRullen & Koch, 2003)。近期,诸多研究表明,注意并非连续地而是 间歇性地加工外界信息(Busch & VanRullen, 2010; Landau & Fries, 2012; Song, Meng, Chen, Zhou, & Luo, 2014; VanRullen, Carlson, & Cavanagh, 2007)。注意 的这种特性被称为"注意的离散性",指在精细的时 间尺度上,注意间歇性地采集外界信息的特性,即 "采集"、"停止"、"采集"、"停止"……如此循环往 复(VanRullen et al., 2007)。该特性在行为上表现为 指标(正确率或反应时)有规律地时高时低,这种由 于注意导致的行为指标有规律的变化被称为注意 振荡(attention oscillation)。新近研究采用高时间分 辨率的行为学研究方法,打破了传统认知任务不能 精细研究注意离散性的局限,直接在被试的行为中 (探测正确率和反应时)发现了振荡模式(Benedetto, Spinelli, & Morrone, 2016; Chen, Wang, Wang, Tang, & Zhang, 2017; Dugué, Marque, & VanRullen, 2015; Dugué, McLelland, Lajous, & VanRullen, 2015; Dugué, Roberts, & Carrasco, 2016; Fiebelkorn, Saalmann, & Kastner, 2013; Huang, Chen, & Luo, 2015; Landau & Fries, 2012; Song et al., 2014)。

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在,并采用 EEG 和 MEG 发现了神经振荡与注意振 荡的密切关系(Busch & VanRullen, 2010; Buschman & Kastner, 2015; Landau, Schreyer, van Pelt, & Fries, 2015; VanRullen, Zoefel, & Ilhan, 2014; Zoefel & VanRullen, 2017), 但是, 还存在两方面的问题: 第 一, EEG 和 MEG 技术存在部分局限(例如, 空间分 辨率低、信号失真)(陈艾睿, 唐晓雨, 王爱君, 张明, 2017); 第二, 现有研究发现的脑区位置相互冲突。 研究使用 EEG 技术发现了注意振荡与额中央区的 神经活动相关(Busch, Dubois, & VanRullen, 2009; Busch & VanRullen, 2010); 而 Landau 等(2015)通过 脑磁图技术探查到对侧半球距状沟、舌回以及楔前 叶等脑区的神经振荡¹与注意振荡密切关联,神经 振荡可能是注意振荡的神经机制(Landau et al., 2015)。 诚如 VanRullen (2016a, 2016b) 指出, 现有研 究并不能说明注意离散性究竟源于脑内的何处位 置、与何种大脑结构相关,即注意离散性的神经节 点并不清楚(VanRullen, 2016a, 2016b)。

由视觉通路的解剖特性可知, 双眼朝前的高等 哺乳动物和人的单眼视觉信息是以分离的方式传 输到左右两侧视皮层的。在外侧膝状体的六层细胞 中,来自两眼的信息分别独立投射至不同的细胞层 内。仅当信息传递至初级视觉皮层(Primary visual cortex, V1)时,来自双眼的信息才能产生汇聚 (Hubel & Wiesel, 1977; 寿天德, 2010)。V1 的第四 层细胞(IVc)是大脑皮层接收视觉信号的第一站。此 处,从双眼而来的视觉信号仍和外侧膝状体神经元 一样, 彼此独立, 每一个单眼细胞仅能接受来自一 只眼的信息(同眼条件),另一眼内的信息对它没有 影响(异眼条件)。相比于其他视皮层区域,单眼细 胞仅在 V1 存在, 这些细胞提供了"信号来自哪一只 眼"的信息(Hubel & Livingstone, 1987)。除此之外, V1 还包含大量对双眼的信息均有反应的神经元, 称为双眼细胞, 只有来自同一感受野输入的单眼细 胞信息才汇聚至同一双眼细胞。因此, 若一个现象 在同、异眼中有差异,则说明该现象的神经节点位 于初级视觉皮层的 IVc 层之前(单眼细胞部分); 若 同、异眼没有差别,则表明该现象的神经节点位于 初级视觉皮层的 IVc 层之后(双眼细胞部分)。

Zhaoping (2008)基于此发现了注意突显地图(bottomup saliency map)产生于V1,研究还发现,相比靶子 和干扰物同眼呈现,异眼的情况下被试需要花费更 多时间才能找到原来的靶子,这一差异说明了注意 突显地图在V1 的单眼细胞加工阶段就已经产生了 (Zhaoping, 2008)。此外,同眼异眼呈现的方法还被 广泛用于其他视知觉现象的神经节点的研究中,如 朝向适应(Gilinsky & Doherty, 1969),空间频率适应 (Blakemore & Campbell, 1969),颜色适应(McCollough, 1965),运动后效(Anstis, Verstraten, Mather, & George, 1998),主观轮廓知觉(Paradiso, Shimojo, & Nakayama, 1989),知觉学习(Schoups & Orban, 1996)等。

诸多研究表明内源性注意和外源性注意与初 级视觉皮层(V1)内的神经元激活状态有关(Briggs, Mangun, & Usrey, 2013; Chalk et al., 2010; Pooresmaeili, Poort, & Roelfsema, 2014; Pooresmaeili, Poort, Thiele, & Roelfsema, 2010; Thiele, Pooresmaeili, Delicato, Herrero, & Roelfsema, 2009; Wang, Chen, Yan, Zhaoping, & Li, 2015)。不仅内源性注意可以调控 V1 区域的 神经元激活状态, 外源性注意同样可以增强 V1 区 域内线索化位置对应的神经元的放电频率(Wang et al., 2015)。Dugué 等(2016)使用 TMS 技术干扰 V1/ V2, 发现非线索化条件, 即注意重定向时, TMS 干 扰的区域为靶子加工的脑区和干扰物加工对应的 脑区时, 被试的辨别力在时间维度上呈现出周期性 变化, 但在线索化条件却未发现振荡模式(Dugué et al., 2016), 虽然这与注意离散性的经典研究结果并 不一致,但研究提示了V1/V2可能也在注意离散性 中起到重要作用。

基于视觉通路的解剖特性,本研究采用高时间 分辨率的线索靶子范式,利用双眼分视技术,考察 V1 区在注意离散性中的作用。实验选取平面立体 镜达到同眼和异眼呈现的目的。该装置通过反射原 理,让屏幕左侧刺激进入左眼,右侧刺激进入右眼, 以此独立控制单眼呈现的刺激。当线索和靶子出现 在不同的眼睛内时(异眼呈现),二者分别驱动了V1 内不同的单眼神经元;当二者出现在同一只眼睛内 时(同眼呈现),二者驱动了相同的单眼神经元。考 虑到辨别任务较探测任务更少受反应偏向的影响 (Drewes, Zhu, Wutz, & Melcher, 2015; Dugué, Merriam, Heeger, & Carrasco, 2017; 钱晨灿,刘祖详, 2016), 实验1使用四择一的迫选任务(four-alternative forcedchoice, 4AFC)考察了非双眼分视下注意的振荡,作 为研究的基线条件。实验2则在实验1的基础上操

¹ 神经振荡(neural oscillation)是大脑内神经元的放电形成的, 人脑内存在不同频段的神经振荡,包括 delta、theta、alpha、beta 以及 gamma。这些神经振荡与注意、感知觉、记忆加工的各个 方面有关(Cohen, 2017; 张雪,袁佩君,王莹,蒋毅, 2016)。研 究者发现刺激出现前、刺激出现后 alpha 频段神经振荡的能量、 相位与注意有关(Busch & VanRullen, 2010)。

控线索和靶子呈现的眼间关系,考察同眼呈现、异 眼呈现条件下的注意振荡:1)如果仅当同眼呈现时 注意振荡才会发生,说明注意离散性源于 V1 的双 眼细胞之前的单眼视觉通路之中;2)如果异眼条件 下和同眼条件下都出现了同样的振荡模式,说明注 意离散性源于 V1 的双眼细胞或之后的视觉区。

2 实验1:非双眼分视条件下的注意振荡

2.1 方法

2.1.1 被试

16 名苏州大学本科生参加了实验(男 3 名, 女 13 名), 年龄为 20~25 周岁(*M* = 21.19 岁, *SD* = 1.60), 均为右利手。所有被试视力或矫正视力正常, 无色 盲或色弱。实验后给予被试相应报酬。

2.1.2 实验设计

实验1作为基线条件,考察了非双眼分视条件 下的注意振荡。采用了单因素两水平(空间有效性: 线索化 vs.非线索化)被试内实验设计。根据线索与 靶子呈现位置的异同(空间有效性),分为线索化条 件和非线索化条件。线索化条件是指靶子出现在与 线索的空间位置相同的光栅之上(同侧位置),非线 索化条件是指靶子出现在与线索的空间位置相反 的光栅之上(对侧位置)。

为了探测注意振荡,实验中设置 50 个 SOA 水平,从 100 到 1080 ms 中每间隔 20 ms 取一个水平 (50 Hz 采样频率)。实验中,通过测量每个 SOA 水平 下的正确率,计算出本实验的因变量注意振荡节律。

从任务类型来看,探测任务会更受被试主观标 准的影响,如果被试的判断标准更为冒险,会有较 多的错误反应;而如果标准更为严谨,会有较少的 正确判断,这种反应偏向会污染最终的实验结果。 研究表明,辨别任务相对较少受到判断标准的影响 (Drewes et al., 2015)。本实验优化了注意振荡的实 验方法,将任务改为四择一的迫选任务(4AFC),并 且该任务为辨别任务,被试需要尽量准确分辨靶子 刺激的位置(左上、左下、右上、右下),对反应速 度没有要求。

2.1.3 实验仪器

实验程序采用 Matlab 和 Psychophysics Toolbox-3 编写(Brainard, 1997; Pelli, 1997), 在 Dell Optiplex755 计算机上运行,显示器为 22 英寸 ViewSonic P225f CRT,分辨率为 1024×768,刷新频率为 100 Hz,用 键盘进行按键反应。

2.1.4 实验刺激

实验场景和参数参考 Landau 和 Fries (2012)的 研究(详见图 1A)。所有刺激均呈现在一个灰色背景 之上,灰色背景的亮度是 3.88 cd/m²。被试需要始 终盯住一个白色圆点(直径为 0.5°),此为中央注视 点。同时,被试需要监视着左右两侧的光栅,光栅 直径为4°,光栅距离中央注视点距离(离心率)为5°, 光栅的空间频率为 1.4 c/°,对比度为 100%。为了尽 量减少靶刺激的突显性影响注意振荡,光栅并非静 止而是沿着某一方向运动,每个试次中,两个光栅 运动速度均为 0.7 c/s (Landau & Fries, 2012)。同时 为防止视觉系统适应光栅朝向,运动方向分别独立 从 0°~360°中随机选取,光栅朝向与运动方向垂直 (Landau & Fries, 2012)。同时,每个光栅分别被灰色 十字线(线宽 0.22°)平均分为 4 份:左上、右上、左 下、右下。

线索刺激包含4个白色圆点,圆点的直径为1°,圆点中心距离光栅边缘 1.5°。实验中,线索呈现的时间为 30 ms。靶刺激是指光栅上任一圆形区域内的对比度陡然下降,圆形区域直径为1°。同样为了降低靶刺激的突显性,整个圆形区域内对比度下降的幅度呈高斯分布,此分布的标准差(*SD*)为 0.5°,最大值由一个自适应阶梯法的程序(QUEST)确定(Watson & Pelli, 1983)。靶刺激的呈现时间为 30 ms,靶刺激随机出现在光栅4个区域中的任意一个之中,避免与十字线重叠。

2.1.5 实验流程

本实验在暗室内进行,被试端坐在屏幕前方, 距离屏幕 50 cm,头放在颚托架上。为更好地探测 注意振荡,实验首先采用 QUSET 方法为每一名被 试确定了一个合适的难度,此时被试探测到靶刺激 出现的概率为 50% (阈限测量) (Fiebelkorn et al., 2013; Landau & Fries, 2012); 然后考察线索化和非 线索化条件被试探测视觉刺激能力的周期性变化 (振荡测量)。

靶刺激的明显程度事先在阈限测量阶段确定。 除不呈现线索刺激之外,实验刺激和流程与振荡测 量阶段相同。程序根据被试的反应自动调节靶子位 置的对比度下降的数值。下降得越多靶刺激越明显, 下降得越少靶刺激越微弱。如果被试可以正确判断 位置,则在随后一次的测试中减少对比度的下降程 度,反之,判断错误则升高对比度的下降值。通过这 种方法测出被试探测到靶刺激的合适阈值,即,此 时被试有 50%的机率可以正确探测出靶刺激的位置。



图 1 实验 1 流程和注意振荡结果。(A)实验 1 流程图;(B)在补零扩展、去趋势、汉宁窗滤波之后,通过快速傅里叶变换把行为振荡中的时域变换到频域。图中显示了线索化条件(红色实线)和非线索化条件(蓝色虚线),被试的正确率随时间的变化趋势;(C)线索化条件和非线索化条件各频段的振幅,*表示显著的频段。彩图见电子版,下同。

振荡测量阶段的流程(详见图 1A):每个试次中, 空屏呈现 1000 至 1200 ms 后, 出现两个运动光栅, 随后(即, 光栅呈现 500~1750 ms 后)线索刺激出现 在其中一个光栅的周围(30 ms),间隔100至1080 ms 之后, 靶刺激呈现 30 ms 后消失, 屏幕中继续呈现 注视点和运动光栅等待被试按键反应。此时, 被试 需要完成一个 4AFC 任务:判断靶刺激的位置(即, 靶刺激出现在光栅的哪个方位)。若3s内被试仍不 按键报告,则呈现红色提示语"左下、右下、左上、 右上",让被试猜测刚才靶刺激出现在光栅上的哪 个方位,直至被试按键,该试次结束。为了减少被 试按键难度,我们选择键盘中小键盘部分的"1、2、 4、5"四个按键分别对应光栅上的四个部分。需要 注意的是, 被试可以忽略靶刺激具体出现在哪个光 栅之中, 而仅仅需要判断靶刺激出现在光栅上的哪 个方位。被试按键后,通过在屏幕中心呈现"对"或 "错"字样给予反馈。振荡测量阶段,每名被试共完 成1600个试次,其中线索化条件有50种SOA水平, 非线索化条件有 50 种不同的 SOA 水平, 每种条件 重复16次。为了避免疲劳效应,振荡测量阶段分为 8组,在2~3天内完成。

2.2 数据分析

采用 Matlab 和 CircStat 工具箱分析被试的正确

率(Berens, 2009)。对于每名被试,首先计算出每个 SOA 线索化与非线索化条件下的正确率, 接下来, 将正确率依照 SOA 从 100 至 1080 ms 分线索化和 非线索化进行排列,由此得到被试的探测能力随时 间的变化规律(ACC-SOA 信号),即行为振荡。接下 来,为了分析行为振荡的频谱特性,对每名被试的 行为振荡(即, ACC-SOA 信号)进行频谱分析。具体 来看,每种条件下,在补零扩展(Zero padded)、去趋 势(Detrend)、汉宁窗滤波(Hanned)之后,通过快速 傅里叶变换(fast Fourier transform, FFT)把行为振荡 中的时域变换到频域。由此,便可探知行为振荡中 的振荡信息。除了频率信息以外,为了进一步确定 振荡模式, 计算了线索化与非线索化条件下行为振 荡的相位信息。在傅里叶变换中提取每名被试在每 个频率(0~25 Hz)上的相位信息,随后将线索化与 非线索化条件下的相位相减,得到二者的相位差 (Phase difference), 最后计算出所有被试的相位趋 势(Cross-subject coherence in the phase difference values)。由此,确定每个频率下线索化与非线索化 条件的相位关系,并采用圆形统计(Circular statistics) 中的 Rayleigh tests 检查显著频段的相位信息的不 一致性是否达到显著水平。

以下非参数统计方法。首先,在每个被试每种条件下,随机打乱 ACC-SOA 信号中的时间信息 1000次, 产生 1000 个替代信号(Surrogate signals)。对每个替 代信号,进行上述的 FFT 分析,在每个频率上得到 1000 个替代信号对应的振幅,这些振幅组成了频 域信息的置换分布(Permutation distribution)。采用 置换检验(Permutation test)对置换分布和原始行为 振荡中的振荡信息进行分析,得到每个频率(0~25 Hz)振荡的显著性。由于该置换检验中涉及了多重 比较,采用较为严格的 Bonferroni 法对结果进行矫 正,以防止假阳性结果的出现。

2.3 结果

首先, 实验 1 探究了非双眼分视条件下 4AFC 任务中注意振荡的频率。结果发现,线索化和非线 索化条件下被试的正确率无差别,分别为 62.04% (SD = 8.68%)和 55.01% (SD = 16.00%), 配对样本 t 检验发现二者无显著差异, t(15) = 1.92, p = 0.074, d=0.48,95%CI=[-0.0077,0.15]。更重要的是线索 化位置和非线索化位置的正确率在时程上呈现此 起彼伏的模式。具体见图 1B, 图中红色实线代表线 索化位置正确率随时间的变化, 蓝色虚线代表非线 索化位置正确率随时间的变化。细线表示原始正确 率,对其进行三点平滑之后得到粗线。结果发现, 当 SOA 较短时线索化位置的正确率高于非线索化 位置, 但是随着 SOA 的延长, 这种趋势并非一直保 持, 而是数次发生反转, 出现"此起彼伏"的交替现 象, 该现象称为行为振荡。此振荡则定性地表明注 意在线索化位置与非线索化位置来回切换, 证明 4AFC 的范式仍旧能够探测到注意振荡。

通过傅里叶分析和置换检验发现,行为振荡在 某些频段达到显著水平。具体见图 1C,线索化位置 的振荡在 6.25~8.59 Hz 达到显著水平(p < 0.05),非 线索化位置在 1.56~2.34 Hz (p < 0.05)达到显著水 平。此结果进一步表明实验 1 中注意振荡出现在低 频频段,与前人结果一致(Dugué, Marque, et al., 2015; Fiebelkorn et al., 2013; Landau & Fries, 2012)。

- 3 实验 2: 双眼分视条件下的注意 振荡
- 3.1 方法

3.1.1 被试

16 名苏州大学本科生参加了实验(男 5 名, 女 11名), 年龄为20~25周岁(*M* = 20.75岁, *SD* = 1.43), 均为右利手。所有被试视力或矫正视力正常, 无色

盲或色弱。实验后给予被试相应报酬。

3.1.2 实验设计

实验2考察了分视条件下的注意振荡。采用了 2(空间有效性:线索化 vs.非线索化)×2(眼睛有效 性:同眼 vs.异眼)的被试内实验设计。空间有效性 的操作定义与实验1相同。根据线索与靶子呈现眼 睛的异同(眼睛有效性),分为同眼条件和异眼条 件。同眼条件是指线索与靶子出现在同一只眼睛内, 异眼条件是指线索与靶子出现在不同的眼睛内。

3.1.3 实验仪器

利用平面立体镜把电脑屏幕两侧图像分别反 射到被试的左眼和右眼。其余设备与实验1相同。

3.1.4 实验刺激

与实验1相同。

3.1.5 实验流程

首先,通过调试程序让每名被试调整平面立体 镜成像直至两侧图像很好地在中央位置融合。然后 进行与实验 1 相同的阈限测量和注意振荡测量实 验。图 2 显示了异眼条件的一种情况,即线索出现 在右眼,而靶子出现在左眼。



3.2 数据分析

与实验1中的数据处理与分析方法相同。

3.3 结果

实验 2 采用 4AFC 范式探究同眼和异眼下注意 振荡的规律。结果发现,线索化和非线索化条件下 被试的正确率无差异,分别为 52.53% (*SD* = 11.76%)和 48.37% (*SD* = 14.13%),配对样本 t 检验 发现二者无显著差异, *t*(15) = 1.82, *p* = 0.09, *d* = 0.23, 95%CI = [-0.0072, 0.090]; 同眼线索化条件和 非线索化条件下被试的正确率无差异,分别为 52.27% (SD = 12.03%)和 47.63% (SD = 14.56%), 配 对样本 t 检验发现二者无显著差异, t(15) = 2.02, p = 0.06, d = 0.25, 95%CI = [-0.0025, 0.095]; 异眼线索 化条件和非线索化条件下被试的正确率无差异,分 别为 52.80% (SD = 11.67%)和 49.13% (SD = 13.91%), 配对样本 t 检验发现二者无显著差异, t(15) = 1.53, *p*=0.15, *d*=0.20, 95%CI=[-0.014, 0.088]。通过傅 里叶分析和置换检验发现,无论是同眼还是异眼条 件下,都出现了明显的行为振荡模式(详见图 3A 和 C)。对行为振荡进一步分析发现,两种条件下都发 现了显著的振荡频段。具体来看,同眼条件下,线 索化位置和非线索化位置都在12.50~13.28 Hz达到 了显著水平(p < 0.05) (详见图 3B); 异眼条件下, 线 索化位置的行为振荡同样在12.50~13.28 Hz达到了 显著水平(p < 0.05)、非线索位置的行为振荡则在 11.72~13.28 Hz 达到了显著水平(p < 0.05) (详见图

3D)。由此可知,在线索化与非线索化位置观察到 了明显的行为振荡。为了进一步确定实验 2 中的行 为振荡,对同眼和异眼条件下 12~13 Hz 的相位进 行分析,发现两种条件下,线索化位置与非线索化 位置的相位出现了显著差异(Reyleigh test,同眼条 件 p = 0.012,异眼条件 p = 0.014),且差异在 180° 附近(详见图 4),即线索化与非线索化两个位置出 现了精准的反相位振荡模式。

4 讨论

本研究采用高时间分辨率的线索靶子范式,利 用平面立体镜分视,操纵了被试双眼视像,不仅考 察了双眼分视是否会影响注意振荡(实验 1 vs.实验 2),还进一步考察了线索和靶子呈现在同眼 vs.异 眼对注意振荡的影响(实验 2),以探究初级视觉皮 层 V1 区在注意振荡中的作用。研究结果发现: 1)非 双眼分视条件下(实验 1),注意振荡出现在低频 (2 Hz 和 8 Hz),而分视条件下,注意振荡则出现在更



图 3 实验 2 注意振荡结果。(A)在补零扩展、去趋势、汉宁窗滤波之后,通过快速傅里叶变换把行为振荡中的时域变换到频域。线索靶子出现在同眼时,线索化和非线索化条件下,正确率随时间变化的趋势;(B)线索靶子出现在同眼时,线索化条件和非线索化条件各频段的振幅;(C)线索靶子出现在异眼时,线索化条件各频段的振幅;*表示显著的频段。



图 4 实验 2 中同眼(A)和异眼(B)条件下注意振荡的相位结果。

高的频段(12.5 Hz)。这表明分视会对注意振荡发生的频段产生影响。2)线索靶子出现在同眼还是异眼条件下注意振荡无显著差异。这提示 V1 区双眼视觉通路或者更高级的视觉区可能参与注意振荡。

实验1采用四择一的辨别任务测量了注意振荡, 结果发现注意振荡出现在低频频段,与以往结果一 致(Dugué, Marque, et al., 2015; Fiebelkorn et al., 2013; Landau & Fries, 2012)。值得注意的是,相较 于探测任务,本研究采用的辨别任务可以更好地避 免被试反应标准(激进或保守)的影响(Drewes et al., 2015; Dugué, Merriam, et al., 2017; 钱晨灿,刘祖 详, 2016)。测得的正确率更纯净地反映了被试的注 意或者知觉能力的变化,而非决策标准。除此之外, 在辨别任务中,常见的 2AFC 的辨别任务的随机正 确率为 50%,仅能操控 50%~100%的阈限。而 4AFC 的随机正确率为 25%,此时实验者可以操控的阈限 范围是 25%~100%。此优势有利于研究不同任务难 度情况下,行为振荡模式的不同。

近年来,注意离散性领域的研究结果,极大地 挑战了传统的注意聚光灯理论,注意并非连续的而 是离散的,基于此,VanRullen 等人提出"眨眼聚光 灯"理论,认为注意系统在加工外界信息时是有节 律的,当空间中存在多个物体时,注意有规律地进 行切换,而当仅加工单个物体时,注意也是离散加 工(VanRullen,2013,2016a,2016b;VanRullen et al., 2007,2014)。本研究的结果进一步支持了"眨眼聚 光灯"理论,而且发现双眼分视与否(实验 1vs. 实 验 2)会影响到注意振荡的频段。值得注意的是,如 果仅在一只眼中呈现刺激,人类被试不能够区分该

刺激源自于哪只眼睛、个体意识到的是两只眼睛内 图像的叠加状态(Wolfe & Franzel, 1988)。V1 被认 为是脑皮层中最不可能与意识相关的脑区(Crick & Koch, 1995; He, Cavanagh, & Intriligator, 1996; He & MacLeod, 2001)。所以, 双眼分视和非双眼分视 条件产生的意识状态相同, 两种条件的差异不可能 源于各种意识上的认知因素。Jia, Liu, Fang 和 Luo (2017)使用高时间分辨率的脑电技术,在各种不同 的任务中考察了注意的时空动态特征。他们发现: 1)刺激出现后,头皮表面记录到的抑制性 alpha 波 标识了注意指向的空间位置或者客体,约 200 ms 注意会在物体间切换一次; 2)注意时空动态特征会 受到任务调控, 且观察到脑电的趋势与行为表现相 关,结果说明注意不仅会对焦点处物体进行加工, 在焦点外还会监控其他物体,这一过程是以动态系 列采样的模式工作的(Jia et al., 2017)。这篇研究及 本研究结果都支持了注意的离散性,提示注意以系 列的方式进行工作,且其动态的工作模式会受到 任务类型及刺激呈现眼间条件的影响而进行灵活 调控。

研究采用高时间分辨率的行为学方法证实了 视觉注意的离散性,并且可以体现在正确率、反应 时两个指标之上(Landau & Fries, 2012; Song et al., 2014); 电生理研究证明神经振荡可能是注意离散 性的神经机制(Busch & VanRullen, 2010; Landau et al., 2015)。但是,现有研究并不能说明注意离散性 究竟源于脑内的何处位置,与何种大脑结构相关 (VanRullen, 2016a, 2016b)。本研究利用人眼视觉通 路的解剖学特性,采用双眼分视技术,比较了线索

靶子出现在同眼和异眼两种条件下的注意振荡。同 眼条件, 靶子激活的是线索出现时激活的单眼视觉 通路, 而异眼条件下, 靶子激活的是另外一只眼睛 的单眼视觉通路。结果发现,即使激活的单眼视觉 通路发生变化,注意振荡发生的频段并未改变,这 提示 V1 区的单眼视觉通路可能并未参与注意振 荡。Dugué 等(2016)采用 TMS 技术大范围干扰 V1/V2 区时发现这些区域会对非线索化条件的正 确率产生周期性变化(Dugué et al., 2016), 结合本 研究的结果共同提示,注意振荡可能与 V1 区的双 眼视觉通路或者更高级的视觉区域有关。初级视觉 皮层注意突显图理论指出,人类的初级视觉皮层可 以在视觉信息加工的早期阶段生成视觉突显图,用 以引导空间选择性注意的分布(Zhaoping, 2008)。这 一理论得到了 fMRI、ERP 研究结果的支持, V1 区 的活动可以预测自下而上的注意及分布(Zhang, Zhaoping, Zhou, & Fang, 2012), 而本研究的结果发 现 V1 区还参与注意离散性的表达, 但额顶区是注 意系统工作的重要脑区(Buschman & Kastner, 2015; Buschman & Miller, 2009, 2010), 因此未来研究需 要厘清视觉区是注意离散性产生的直接原因,抑或 是额顶区通过反馈信号使得初级视觉皮层进而表 现出注意离散的特性。

5 结论

(1) 四择一迫选的辨别任务可以探测到明显的 注意振荡。

(2) 双眼分视和非双眼分视条件的注意振荡模 式存在差异,表明分视会对注意振荡产生影响。

(3) 同、异眼条件的注意振荡模式无差异,表明 V1 区双眼视觉通路或者更高级的视觉区可能参与注意振荡。

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The primary visual cortex modulates attention oscillation

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Abstract

It has been well documented that the spotlight of attention is intrinsically rhythmic, which discretely samples a single or multiple objects. Adopting high resolution behavioral approach, attention oscillation has been revealed. However, neural mechanism of attention oscillation remains poorly understood. In the present study, basing on functional anatomy of the primary visual cortex, we aimed to investigate the role of primary visual cortex (V1) in attention oscillation, by using a modified high temporal resolution cue-target paradigm in a 4AFC task.

In the present study, behavioral oscillations in visual attention under ordinary (binocular; not dichoptic) viewing condition (exp. 1) and binocular dichoptic (exp. 2) condition were examined. In experiment 1, 16 paid participants were asked to detect target at either the previously cued (valid condition) or uncued location (invalid condition). The cue-target SOA varied from 0.1 s to 1.08 s in steps of 20 ms. Performances were evaluated in a 4AFC task. If they saw target, they were instructed to judge the location of the target (1 for target on the upper left; 2 for upper right; 4 for lower left; 5 for lower right) on the keypad. While, 16 paid participants were recruited to detect target at either cued or uncued locations under binocular dichoptic condition. Target could occur in the same or different eye of cue stimuli. Amplitude of target contrast decrement was determined with QUEST procedure before cue-target experiment. Except that no cue stimuli were presented, threshold procedure was identical to the cue-target experiment procedure.

Results showed that when grating locations were presented under ordinary viewing condition, a theta rhythm was visible. While targets were presented in the same or different eye under binocular dichoptic condition, attention oscillation was clearly seen at 12.5 Hz with antiphase relationship between cued and uncued conditions.

The findings under ordinary viewing condition are in general consistent with previous studies. While, under binocular dichoptic condition, attention oscillation increased to a higher frequency. This study indicates that attention oscillation may occur at or beyond primary visual cortex where binocular integration begins.

Key words attention oscillation; V1; binocular dichoptic; high temporal resolution; cue-target paradigm

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样例类型与解释方式对初中生数学 概率问题解决的效果*

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摘 要 为考察样例类型与解释方式对初中生数学概率问题解决的促进作用,实验1随机选取初中生90名,比较正确样例组、正 误样例组、对照组的学习效果,实验2随机选取另外90名初中生,比较有教学解释、有自我解释与无解释的正误样例组的即时与 延时测试学习效果,研究发现:(1)正误样例学习效果显著好于正确样例;(2)有解释的正误样例学习效果显著好于无解释的 正误样例;(3)与有教学解释的正误样例学习效果相比,有自我解释的正误样例学习效果显著且更持久。 关键词 正确样例 正误样例 教学解释 自我解释 数学概率问题解决

1 引言

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样例是一种呈现专家问题解决过程以便于学生 蓂仿掌握的教学工具。它由问题情境、问题解决步骤、 答 案 构 成 (Renkl, Stark, Gruber, & Mandl,1998)。 早在上世纪 80 年代国内外研究就表明,与练习相 比,样例学习能减轻学生外在与内在认知负荷, 学 习 效 果 更 好 (Cooper & Swell, 1987; Swell & Cooper, 1985; Sweller, Ayres, & Kalyuga, 2011; Zhu & Simon,1987)。Chi, Bassok, Lewis, Reimann 和 Glaser(1989)发现主动加工的学生比被动加工的学生 从样例学习中受益更多,进而提出样例设计不仅要 考虑学生认知负荷,还应引发学生积极主动加工。

不完整样例让学生主动填补缺损步骤,其学 习效果显著高于完整样例(林洪新,张奇,2007; Renkl,2002),但不完整样例的步骤缺损会增加学 生内在认知负荷,难以填补步骤(Hilbert, Renkl, Kessler, & Reiss, 2008)。针对此不足,有研究者提 出正误样例学习,即比较正确与错误样例,认为正 误样例比较关涉学生深度认知加工,学生在出现错 误时学习收获会更大(Booth, Lange, Koedinger, & Newton, 2013; Durkin & Rittle-Johnsonet, 2012)。不 同知识领域、不同组合的正误样例学习效果不完全

一致。Große和Renkl(2007)比较正确样例与正误 样例学习效果,采用先正确再错误样例的序列方式 多步骤呈现数学概率的正误样例组合,并且无错误 标记,结果显示,正误样例组合只提高有较多相关 数学知识学生的学习效果,相关数学知识较少的学 生难以找到与分析错误样例中的错误,学习效果不 佳。许德志和张奇(2011)以高一化学烃类物质碳 氢共价键结构式为实验材料探讨正误样例学习效果, 发现正误样例数量相等或配对时学习效果更好。张 奇与张华(2014)以初三物理物体受力分析为实验 材料, 通过3个实验探讨正误样例学习效果, 发现 仅呈现正误样例并不能让学生找到错误样例的错误 之处,有错误标记的正误样例配对学习效果更好。 基于不完整样例设计与正误样例设计的不足,有研 究者提出应在呈现样例同时给予解释以更进一步提 高样例学习效果。

解释包括教学解释(样例呈现同时给予解释) 与自我解释(呈现样例让学生自己进行解释)。很 多相关研究发现教学解释更能促进学生样例学习(林 洪新,张奇,2007;张华,曲可佳,张奇,2013;张奇, 郑伟,万莹,2014; Reed & Bolstad, 1991; Renkl, 2002),但也有研究认为教学解释对样例学习影

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响有限 (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003; Gerjets, Scheiter, & Catranboneet, 2006; Witter & Renkl, 2010)。自我解释对样例学习效果的研究发 现自我解释让学生受益更多,尤其是陈述解题步骤 与理由的自我解释 (Hausmann, Nokes, VanLehn, & Gershman, 2009; Hausmann & VanLehn, 2007)。但 Hilbert 等(2008)发现,有自我解释的不完整样例 学习增加学生更多内在认知负荷,其效果不如不完 整样例。Chi, De Leuuw, Chiu 和 Lavancher (1994)指 出, 与领域知识少的学生相比, 领域知识多的学生 会进行更多自我解释,学习效果更好。张奇和林楠 (2014)提出样例学习中自我解释效应高低受学生 先行知识、一般能力与个体差异的因素影响。有自 我解释与有教学解释的样例学习比较中, 有些研究 发现有教学解释的样例学习效果要好于有自我解释 的样例学习,因为学生有时并不知道自己解释是错

误的,将教学解释与样例同时呈现给学生能有效减 少他们的认知负荷同时让学生主动加工正确解释 (Lee & Anderson, 2013; Renkl, 2002)。也有研究发 现有教学解释和有自我解释的样例学习效果相同甚 至后者学习更好,因为后者需要学生积极主动加工 样例(徐碧波,林崇德,杨永宁, 2010; Schworm & Renkl, 2006; Witter & Renkl, 2010)。教学解释时, 教学实践者很深的体会就是学生-教就懂,一做就 错,教学解释对学生学习的长期影响不显著。徐碧 波等(2010)采用2(样例呈现顺序:先抽象后具体、 先具体后抽象)×2(解释方式:给予教学解释、引 发自我解释、自发自我解释)实验设计,样例学习 效果采用即时与延时后测,他们发现,无论即时还 是延时后测,给予教学解释与引发自我解释的效果 无显著差异,只有在先具体后抽象呈现样例时,引 发自我解释的延时后测要显著高于教学解释。

基于已有样例学习研究结论歧异,针对不同学 科领域的正误样例学习效果不一,化学、物理正误 样例学习效果显著(许德志,张奇,2011;张奇,张华, 2014),而数学正误样例学习更加适合相关数学知 识更多的学生 (Große & Renkl, 2007); 针对样例 学习中自我解释和教学解释学习效果的研究结论歧 异,本研究选择初三数学概率问题,分别进行正确 样例、正误样例的比较,在此基础上再进行无解释、 有教学解释与有自我解释的正误样例的即时与延时 测试比较,我们假设:(1)正误样例学习效果要好 于正确样例; (2) 在即时与延时测试上, 有解释的

正误样例学习效果要好于无解释的正误样例,有自 我解释的正误样例学习效果要好于有教学解释的正 误样例,或者有教学解释的正误样例学习效果要好 于有自我解释的正误样例。

实验研究 2

2.1 实验1 正确样例与正误样例对初中生概率问题 解决的影响

21.1 被试

从某市一普通中学初三年级平行班中随机抽取 3个班级,每班随机抽取 30 名学生作为被试,男女 生比例大致相当,将被试随机分配到正确样例组、 正误样例组与对照组中。

实验前收集所有被试最近一次概率测验成绩, 单因素方差分析表明,三组被试成绩之间没有显著 差异(F(2,87)=.21, p=.81),说明三组被试前期概 率知识掌握程度相当。

2.1.2 实验设计

采用单因素被试间实验设计,设置实验组和对 照组,自变量为样例类型,分为正确样例与正误样例, 因变量是问题解决正确率。

2.1.3 实验材料

选取概率知识作为实验内容。通过与一线数学 教师、教研组长和教研员访谈,选择"不理解古典 概率两个特征"、"混淆抽样中的放回与不放回"、 "忽视等可能性"等3个初三学生容易犯错的知识点, 之后与他们共同讨论, 编制样例学习材料与相关概 率问题的测试材料。

(1) 样例学习材料的编制

"正确样例组"包含4 道概率问题,每道都给 出正确解法。"正误样例组"包含4道概率问题, 每道例题成对并列呈现一正确解法与一错误解法。

(2)测试材料的编制。包含8个概率问题,根 据样例学习材料中4道例题所考察知识编制。每道 题满分5分,分步骤计分,其中步骤①为3分(该 步骤涉及重要知识点),步骤②为1分,步骤③为1分, 答错或不答0分。测试满分40分。请三位初三数学 教师对测试材料进行难易评定,8道题目中第1、2、 5、6、7道难度较易,第3、4、8道较难。

样例学习材料和测试材料均打印在 210mm×297mm的白纸上,字体为宋体五号。 2.1.4 实验程序

三组被试分别在三间教室内同时进行, 被试同

空一座位。实验过程中,被试间不进行任何交流。 实验分为样例学习和测试两个阶段。

(1)样例学习阶段。"正确样例组"学习正确 样例;"正误样例组"学习正误样例;对照组休息, 不学习任何材料。样例学习阶段时长为 25 分钟,学 习完毕收回样例材料。

(2)测试阶段。所有被试完成 8 个概率问题解 决,其中两个实验组指导语为:"请你根据刚才从 学习材料中总结出的解题规则完成以下 8 道题目"。 对照组指导语为:"请你完成以下 8 道题目"。测 试时间为 25 分钟,被试确定写完可以提前交卷。

2.1.5 三组被试测试成绩的差异性比较

24		一组放风侧风风坝的半均级和标准差
 	-	

-	样例学习类型	n	М	SD
	正确样例组	30	22.53	7.44
	正误样例组	30	26.30	7.04
1. Contraction of the second	对照组	30	20.57	6.91

单因素方差分析结果表明, 三组被试测试 成绩之间存在显著差异(F(2,87)=5.00, p=.01, η^2 =.103)。LSD事后多重比较表明:正误样例学 习组成绩显著高于正确样例组(p=.04);正误样例 学习组成绩要显著高于对照组(p=.00);正确样例 学习组与对照组测试成绩之间差异不显著(p=.29)。 2.2 实验2正误样例学习中不同解释方式对初中生 概率问题解决的影响

2.2.1 被试

实验2选择另外90名被试,随机分成三组,每 组30人。抽取方法与实验1同,实验前收集所有被 试最近一次概率测验成绩,单因素方差分析表明, 三组被试概率测验成绩之间不存在显著差异(F(2, 87)=.18, p=.83),说明三组被试前期概率知识掌握 程度相当。

2.2.2 实验设计

实验采用单因素被试间设计,设置三个实验组。 自变量为解释方式,分为自我解释、教学解释与无 解释方式。因变量为问题解决正确率,包括即时与 延时概率问题测试成绩,以考察不同解释方式效果 及其持久性。

无解释组只提供四道正误样例题,每道例题成 对并列呈现正确解法和错误解法。自我解释组提供 相同四道正误样例题,但在错误解法旁给出提示性 思考问题。教学解释组提供相同四道样例题,但在 错误解法旁给予错误原因的分析解释(自我解释组 提示性问题的答案)。

2.2.3 实验材料

实验内容与实验1同。

(1)样例学习材料的编制。样例为正误样例,
每道例题成对并列呈现正确解法和错误解法。"自我解释组"在每道例题的错误解法旁给出3个提示性思考问题,如在关于"等可能性"的正误样学习中,在错误样例旁给出的提示性思考问题是:"以上3个解题步骤中哪个步骤是错误的?"、"这9种结果的出现是'等可能'吗?你判断的依据是什么?"、"如果要避免解题错误需要注意些什么?"等。"教学解释组"则直接在每道例题错误解法旁给出错误原因的分析解释。"无解释组"的学习材料与实验1的"正误样例组"学习材料一样。

(2)测试材料的编制。即时与延时测试材料相同,都运用实验1的测试材料。测试材料同一性主要基于以下考虑:测试目标是比较不同解释方式下样例学习效果的持续情况,而概率问题多为生活情境问题,即便即时与延时测试题目构成类似,但具体问题情境不同会产生新知识信息,导致学生更多认知负荷,引起加工困难,产生无关变量与自变量的混淆。本研究即时与延时测试采用同样材料,既避免新知识信息造就学生认知负荷增加,也保障即时、延时测试数据之间的同一,便于两者间的比较。

样 例 学 习 材 料 和 测 试 材 料 均 打 印 在 210mm × 297mm 的白纸上,字体为宋体五号。 2.2.4 实验程序

实验分为样例学习和测试两个阶段,三组被试 分别在三间教室中同时进行。

(1)样例学习阶段。"无解释组"与实验1的 "正误样例组"学习任务一样。要求"自我解释组" 被试比较正误样例并写下每道提示性问题的答案。 要求"教学解释组"被试比较正误样例并理解错误 解法旁的教学解释。每组被试学习时间最长为25分钟。

(2)测试阶段。分为即时与延时测试。即时测 试在回收学习材料后马上将测试材料发给学生。延 时测试在两周后进行,让同一被试再次完成即时测 试材料,完成时间 25 分钟。

2.2.5 不同解释方式被试即时与延时测试成绩的差 异性比较

单因素重复测量方差分析显示: (1) 解释方

式对学习成绩有显著影响 ($F(2, 87)=4.99, p=.009, \eta^2=.103$)。配对比较表明,自我解释组成绩显著高于无解释组 ($M_{自我解释}=32.30, SD_{自我解释}=1.21; M_{\pi}$

= 0	不同解释方式被试即时与延时测试成绩的平均数和标准差
モン	

		M	SD)
解释方式	n	即时	延时
	30	31.63 (6.97)	32.97 (6.51)
有自我解释的正误样例学习组		30.67 (6.71)	28.23 (6.67)
有教学解释的正误样例学习组	30	50.07 (0.02)	27.20 (6.97)
无解释的正误样例学习组	30	26.63 (7.08)	

前者高于后者;自我解释组与教学解释组测试成绩 之间差异不显著 (p=.59)。(2)测试时间对学习 成绩没有显著影响,即时和延时测试结果之间没 有显著差异 ($M_{\text{即时测量}}=29.64, SD_{\text{即时测量}}=.73; M_{\text{延时}}$ $_{\text{测量}}=29.47, SD_{\text{时测量}}=0.71; p=.622$)。(3)解释方 式和测试时间之间存在交互效应 (F(2, 87)=10.25, $p=.000, \eta^2=.191$)。简单效应检验发现,只有教 学解释组即时和延时测试成绩之间存在显著差异 (t=3.24, p=.003),即只有教学解释组正误样例学 习效果两周后显著下降。自我解释和无解释组的学 习效果两周后无显著变化,继续保持原来学习水平。

针对教学解释组学习效果两周后出现明显衰减, 把实验2即时和延时测试结果分别进行方差分析, 结果表明:(1)自我解释组与教学解释组即时测 试成绩之间没有显著差异(p=.59),但都显著高于 无解释组(p=.01, p=.03)。(2)教学解释组与无 解释组延时测试成绩之间没有显著差异(p=.55), 但都显著低于自我解释组延时测试成绩(p=.01, p=.00)。

综上,实验2研究结果为:(1)引发自我解释 的正误样例学习效果显著好于教学解释和无解释组, 并且更加持久,优势至少保持两周。(2)教学解释 组样例学习即时成绩优于无解释组,此优势两周后 出现明显衰减,学习效果(延时成绩)与无解释组 持平。(3)自我解释组、无解释组的正误样例学习 效果,两周后没有显著变化。

3 结果讨论

3.1 正误样例学习效果显著高于正确样例学习

本结果与已有很多研究结果一致,即正误样例 学习效果显著好于正确样例学习(张奇,张华, 2014; Booth et al., 2013; Durkin & Rittle-Johnson,

2012)。VanLehn(1999)的"障碍—驱动学习"理 论指出,错误引起学生反思,加深其对知识的正确 理解。本研究成对并列呈现正误样例,学生可能通 过对照比较,发现并分析错误步骤,认识知识应用 条件,从而加深对问题及相关知识的理解。而仅呈 现正确样例,无对照比较过程,即使学生有更多时 间观察模仿正确样例,但对知识应用条件没有充分 理解,一旦问题情境发生变化,学生仍会出现错误。

本研究与 Große 和 Renkl(2007)的研究结果不一 致,可能是因为 Große 和 Renkl 的研究是条例呈现 正误样例,即先正确后错误样例,学生需先识记正 确样例解题步骤,再观察错误样例步骤,然后比较, 增加其内外认知负荷,最终学习效果较差。本研究 并列呈现同一问题情境的正误样例组合,减少学生 内外认知负荷,学生可对同一问题的正误解法直接 进行比较,分析错误原因、纠正错误理解,最终提 高样例学习效果。另外 Große 和 Renkl 选择的概率 问题较复杂,解题步骤繁多,问题难度也很大,而 本研究概率问题的解题步骤控制在三步(实验1测 试成绩均分为 23.13,难度为 .58),学生内外认知 负荷较少,使得大多数学生能从正误样例学习中获 益。

3.2 有解释的正误样例学习效果显著好于无解释, 且自我解释效果更好且更加持久

部分研究发现,有教学解释的样例学习效 果好于有自我解释与无解释的样例学习(Lee & Anderson, 2013; Renkl, 2002),但本研究实验2发现, 即时测试中,有自我解释与教学解释的正误样例学 习无显著差异,且都显著好于无解释;但延时测试 却发现,有自我解释的正误样例学习效果显著高于 有教学解释与无解释,且后两者在延时测试上无显 著差异。本研究与徐碧波等(2010)存在差异。徐 碧波等(2010)则发现教学解释与自我解释在即时 后测与延时后测中无显著差异,只有在先呈现具体 样例再呈现抽象样例时,自我解释的延时后测要显 著高于教学解释。原因可能是本研究是并列成对呈 现正误样例,减少学生认知负荷,让他们有更多认 知资源进行自我解释;而徐碧波等的研究只有在先 具体后抽象呈现样例时才减轻学生认知负荷,使得 他们能进行自我解释。

为什么有自我解释的正误样例学习效果最好且 持续时间更长? Chi 和 Wylie (2014)的学生学习行 为 ICAP 理 论 (interaction-construction-active-passive learning theory)认为学生互动行为最有利于学习, 其次是建构学习行为、主动学习行为,学生被动学 习行为最不利。根据 Atkinson 和 Renkl (2007) 的观点, 自我解释的正误学习样例设计是在错误样例的错误 步骤上进行提问或提示,会引发学生更多互动、建 构与主动学习行为,因此无论是即时还是延时测试, 其成绩都要显著高于无解释和有教学解释的正误学 习样例。有教学解释的正误样例学习考虑到有学生 可能不会或难以进行正确对照比较,因此在错误样 例的错误步骤处增加解释,使得其即时成绩与有自 我解释的正误样例学习无显著差异,但要显著高于 无解释的正误样例。但由于教学解释使学生更多主 动学习行为较少建构学习行为,最终导致延时测试 成绩要显著低于有自我解释的正误样例,与无解释 的正误样例无显著差异。

4 结论

4.1 正误样例学习效果显著好于正确样例。

4.2 有解释的正误样例学习效果显著好于无解释的 正误样例。

4.3 与有教学解释的正误样例相比,有自我解释的 正误样例学习效果显著且更持久。

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Different Style of Worked Example and Explanation: The Efficiency to Statistics Problem Solving in Middle School

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Abstract Researchers should consider not only students' cognition load but their active cognitive processing when designing example in example learning. Research on fading example and correct - incorrect paired example showed that both of them can improve students' learning in near transfer but can't let every student be involved in active processing. Because of those shortcomings, some researchers pointed out that in order to initiate students' active processing in example learning, explanations should be given to students with examples at the same time. But contradictory conclusions were gotten with comparative studies on example learning between with and without teaching explanation, those between with and without self-explanation.

Because contradictory conclusions were reached in the research on different explanations in example learning, fading example was chosen in most of example learning studies, and it increased students' cognition load. In our research, we chose correct - incorrect paired examples in order to compare the efficiency of correct example and correct-incorrect paired examples, compare the efficiency of self-explanation, instruction explanation, no explanation. We chose probability problems in mathematics in Grade 9 and designed learning materials of experiment 1 and experiment 2, instant post-test and delayed post-test. In experiment 1, between-subject experiments are designed to compare the influence of correct example and correct - incorrect paired example on probability problem solving. 90 students were assigned randomly to correct example group, correct-incorrect example group and control group. The results showed that students' test performance in correct - incorrect paired example group are significantly higher than that of the students in correct example and control group. There are no significant differences of students' performance in correct example group and control group. In experiment 2, the between- subject experiments are designed to compare the influence of different explanations (instruction explanation, self-explanation, no explanation) on probability problem solving in correct - incorrect example learning. 90 students were assigned randomly to self-explanation group, instruction explanation group and no explanation group. The results showed that students' performance in selfexplanation group and instruction explanation group is significantly higher than that of the students in no explanation group in instant post-test and there are no significant differences of students' performance between instruction explanation group and self-explanation group. But students' performance in self-explanation group is significantly higher than that in students in instruction explanation group and no explanation group in delayed post-test, and there are no significant differences of students' performance between instruction explanation group and no explanation group in delayed post-test.

The conclusions are that (1) Correct-incorrect paired example is significantly more effective than correct example in statistics problem solving; (2) Correct - incorrect paired example with explanation is significantly more effective than correct - incorrect paired example without explanation; (3) Correct - incorrect paired example with self-explanation is significant better and lasted longer than correct - incorrect paired example with instruction explanation.

Key words correct example, correct-incorrect paired example, instruction explanation, self-explanation, statistics problem solving

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Instructor-learner brain coupling discriminates between instructional approaches and predicts learning

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Instructor-learner brain coupling discriminates between instructional approaches and predicts learning



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ABSTRACT

The neural mechanisms that support naturalistic learning via effective pedagogical approaches remain elusive. Here we used functional near-infrared spectroscopy to measure brain activity from instructor-learner dyads simultaneously during dynamic conceptual learning. Results revealed that brain-to-brain coupling was correlated with learning outcomes, and, crucially, appeared to be driven by specific scaffolding behaviors on the part of the instructors (e.g., asking guiding questions or providing hints). Brain-to-brain coupling enhancement was absent when instructors used an explanation approach (e.g., providing definitions or clarifications). Finally, we found that machine-learning techniques were more successful when decoding instructional approaches (scaffolding vs. explanation) from brain-to-brain coupling data than when using a single-brain method. These findings suggest that brain-to-brain coupling as a pedagogically relevant measure tracks the naturalistic instructional process during instructor-learner interaction throughout constructive engagement, but not information clarification.

1. Introduction

Humans have evolved the ability to learn through social interaction with others (e.g., an instructor), an important skill that serves us throughout our lifespan (Verga and Kotz, 2019; Pan et al., 2018). Such interactive learning is thought to be facilitated by instructional tools, like demonstrating rules or providing examples for practice. Verbal instruction has been shown to play an enabling and modulatory role in learning at multiple levels, ranging from functional brain re-organization (Hartstra et al., 2011; Olsson and Phelps, 2007; Ruge and Wolfensteller, 2009) to learning performance optimization (Clark and Mayer, 2016; Wolfson et al., 2014). However, despite the dynamic and interactive nature of instruction-based learning, neurobiological research investigating learning through instruction has been mostly limited to controlled laboratory studies - stripped from any real-time interaction between the learner and the instructor (e.g., Ruge and Wolfensteller, 2009) - and have often ignored the role of different instruction approaches (e.g., Holper et al., 2013). As a result, the brain mechanisms that support dynamic interactive learning remain understudied, and thus poorly understood.

Recent methodological advances (Brockington et al., 2018; for a review, see Hasson et al., 2012) have allowed researchers to begin investigating the neural basis of naturalistic instruction-based learning (Bevilacqua et al., 2019; Dikker et al., 2017; Liu et al., 2019; Pan et al., 2018). In the past few decades, (social) neuroscience has seen an "interactive turn" (Babiloni and Astolfi, 2014; Leong and Schilbach, 2019): an increasing number of researchers within social psychology, (educational) neuroscience, and psychiatry have begun comparing brain activity across individuals using a variety of methods (e.g., fMRI: Bilek et al., 2015; Montague et al., 2002; EEG: Babiloni et al., 2006; Dumas et al., 2010; Tognoli et al., 2007; fNIRS: Cui et al., 2012; Jiang et al., 2015; Pan et al., 2018). These work mostly entails the simultaneous measurement of brain activity of (two or more) socially interacting individuals, which is termed as "hyperscanning" (also aligns with the "second-person neuroscience", Redcay and Schilbach, 2019; Schilbach et al., 2013). The transition from a stimulus-brain to a brain-brain approach has been driven both by neuroscientists who are interested in

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studying naturalistic perception (e.g., Hasson et al., 2004) as well as scholars whose goal is to investigate the social brain *during* real-time social interaction (e.g., Dumas et al., 2010; Schilbach et al., 2013; for reviews see Hasson et al., 2012; Babiloni and Astolfi, 2014; Redcay and Schilbach, 2019).

Previous studies that fall within the second category have suggested that the interaction between instructor and learner is reflected in the extent to which brain activity becomes 'coupled' between them (Bevilacqua et al., 2019; Holper et al., 2013; Pan et al., 2018; Zheng et al., 2018). For example, brain-to-brain coupling has been reported to reliably predict the success of social interactive learning (Pan et al., 2018). However, while some studies have shown such a relationship between brain-to-brain coupling and learning outcomes (e.g., Holper et al., 2013; Liu et al., 2019; Pan et al., 2018; Zheng et al., 2018), others did not in fact observe a correlation between teacher-student brain-to-brain coupling and content retention (e.g., Bevilacqua et al., 2019). One potential limitation of most prior studies on learning concerns that they only focused on the average brain-to-brain coupling across the entire teaching session and its relation with learning outcomes (Davidesco et al., 2019). It is possible that linking specific moments of brain-to-brain coupling (such as those associated with certain instructional behavior) to learning might vield complementary useful information (Pan et al., 2018).

Here, we further investigated the functional significance of brain-tobrain coupling in learning and instruction. In addition to examining whether brain-to-brain coupling between instructors and learners can predict learning outcomes, we asked whether brain-to-brain coupling can be used to classify instructional dynamics during interactive learning. Such a finding would suggest that brain-to-brain coupling may be a pedagogically informative implicit measure that tracks learning throughout ongoing dynamic instructor-learner interactions.

An influential theoretical model to account for learning during ongoing instructor-learner interactions is the Interactive-Constructive-Active-Passive theory (ICAP, Chi and Wylie, 2014). The ICAP theory distinguishes between different cognitive engagement activities during learning interactions. Specifically, it posits that *constructive* engagement behaviors (e.g., learners generate their own understanding from instructors' guidance) compared to *passive* engagement behaviors (e.g., learners passively receive knowledge from instructors) require more bidirectional exchange between instructors and learners, and promote learning better.

On the basis of this ICAP hypothesis, we distinguished two common (and also classic) instructional strategies - explanation and scaffolding which map onto the passive and constructive engagement modes respectively. First, the "explanation-based" approach assumes that learning emerges as a result of information clarification, which serves to enhance learners' comprehension (Chi, 2013; Duffy et al., 1986). In this approach, instructional modulation of learning is driven by meaningful explanatory information. Yet, instructional explanations are usually conceived of as prefabricated information that learners might only passively receive, without further engagement in elaborative activities (Wittwer and Renkl, 2008). A second line of instructional approaches emphasizes the importance of supportive scaffoldings provided by the instructor. Scaffolding involves many constructive engagement behaviors, including asking key questions (e.g., asking learners their understanding of a core concept) and providing hints (e.g., giving an analogy of the learning content) that are aimed at redirecting learners' actions and understanding (Van de Pol et al., 2010). Scaffolding foregrounds bidirectional communication and information sharing - both instructors and learners are involved in a two-way dynamic process of receiving and sending out information.

In addition to instructional strategy, adaptive behavior on the part of the instructor has also been shown critical for interactive learning (Chi, 2013; Chi and Roy, 2010). That is, the instructor provides personalized guidance based on the learner's current level of knowledge (Wass and Golding, 2014). We therefore added a second dimension to our study design where half of the instructors were informed of the learner's knowledge level based on their performance on a pre-test (personalized instruction) and half of them were not informed (non-personalized instruction).

Twenty-four instructor-learner dyads participated in a concept learning task, during which their brain activity was recorded simultaneously with functional near-infrared spectroscopy (fNIRS; Cheng et al., 2015; Pan et al., 2018; Zheng et al., 2018). Brain-to-brain coupling between instructors and learners was first estimated using Wavelet Transform Coherence (Grinsted et al., 2004), and then correlated with learning outcomes (to explore the brain-behavior relationship). The ICAP theory predicts that scaffolding-based learning requires more bidirectional communication and information sharing. Thus, we hypothesized that scaffolding-based learning would be associated with increased instructor-learner brain coupling compared to explanation-based learning. A video coding analysis allowed us to further parse whether the brain-to-brain coupling in instructor-learner dyads was specifically driven by certain instructional behavior. To the extent that the ICAP theory holds true, we expected that constructive/scaffolding instructional behaviors to contribute more to instructor-learner brain coupling than non-scaffolding behaviors. Finally, to identify to what extent scaffolding strategies can be distinguished from explanation strategies in the neural data, we used a decoding analysis. We employed the same decoding approach on both brain-to-brain coupling and individual brain data to explore the possible added value of a two-brain vs. single-brain analysis. This third measure was motivated by a growing number of two-person studies indicating that brain-to-brain coupling serves as a good neural-classification feature (Dai et al., 2018; Jiang et al., 2012, 2015).

2. Methods

2.1. Participants

Twenty-four dyads (n = 48, all females, mean age = 21.46 \pm 2.75 years) were recruited to participate in the study. Each dyad consisted of one learner and one instructor. Each instructor taught the learner in a one-to-one way. The instructors (mean age = 22.58 ± 2.75 years) had all received graduate training in psychology, had at least 1-year of instructional experience, and were familiar with the learning content, whereas the learners (mean age = 20.33 ± 2.30 years) in our sample majored in non-psychology related fields and had not been exposed to the content. All participants were healthy and right-handed and were recruited through advertisements. Each participant gave informed consent prior to the experiment and was paid for participation. The study was approved by the University Committee of Human Research Protection (HR 044-2017), East China Normal University.

2.2. Tasks and materials

The task used in the present fNIRS-based hyperscanning study was a conceptual learning task, which involved mastering two sets of materials, each explaining four psychological terms pertaining to an overarching concept. The material was chosen to be novel and attractive to nonpsychology majors and teachable within 10-20 min. The sets centered around the concepts of reinforcement and transfer. These concepts were chosen from a classic national standard textbook (Educational Psychology: A Book for Teachers). These two concepts belong to the similar topic (i.e., learning psychology) and occupy a similar instructional period (i.e., 1~2 sessions). The reinforcement set consisted of teaching positive reinforcement, negative reinforcement, punishment, and retreat (Set 1), and transfer consisted of near-transfer, far-transfer, lateral-transfer, and vertical-transfer (Set 2). This design allowed us to provide different learning content for the two within-participant instructional strategies (i.e., scaffolding vs. explanation), without repeating any content. Learning outcomes did not differ between the two sets of concepts, and were thus pooled together in the results reported below.

All instructors were informed and trained by experimenters two days prior to the experiment. Training examples were selected from the textbook's training section. Each example consisted of instructional goals, instructional difficulties, general instructional processes, and detailed instructional scripts. Such instructional scripts were composed and adapted with the help of two psychological experts with at least 20 years of instructional experience at the university level. The detailed instructional scripts were provided in order to control the instructional process, and to maintain the consistency of the number of questions and the concepts across all the participant dyads. Instructors were required to prepare instruction at home for 2 days. They then practiced with each other in the lab until they were satisfied with their own instructional performance in both the scaffolding and explanation conditions (they spent approximately the same amount of time training for both types of instructions). Then they demonstrated instruction to the experimenter in a one-to-one way until their performance met the established standard requirements: the length of teaching, the speed of speech, and consistency with the instructional processes and scripts (Liu et al., 2019).

2.3. Experimental factors

We manipulated one within-participant variable and one betweenparticipant variable. The within-participant variable was the Instructional Strategy (scaffolding vs. explanation). Following the scripts, the instructor using a scaffolding strategy would guide the learner in a Q&A manner along the following lines (one representative example, translated from Chinese):

- Instructor: How can one provide positive reinforcement?
- Learner:By rewarding positive behavior?
- Instructor: Bingo! Could you please give an example?
- Learner: My sister gave me some candies after I cleaned my room.

For the explanation strategy, the instructor would explain each concept to the learner and provide examples. The following interaction provides a representative example of explanatory behavior:

- Instructor: Positive reinforcement refers to rewarding goal-directed behavior to increase its frequency. Do you see what I mean?
- Learner: I am not sure whether I understand it correctly. Could you please explain it a bit more?
- Instructor: For example, my mom cooks my favorite food for me when I pass exams.
- Learner: That clarifies it.

.....

The between-participant variable was Instructional Personalization (personalized vs. non-personalized; i.e., whether the instructor customizes their instructions to the learner's aptitude and ability as established via a pre-test). Instructions might be intrinsically personalized: for example, instructors often monitor learners' comprehension and guide their understanding during face-to-face interactions. For instructors to be able to customize their instructions, learners have to inform them about their lack of understanding. Therefore, we exogenously manipulated Instructional Personalization. For half of the participants (n = 12 dyads), the learner's pre-test results (i.e., prior knowledge level) of the eight concepts (4 from Set 1 and 4 from Set 2) were provided to the instructor. The instructor was then asked to adapt their instruction to suit the needs of each learner (e.g., allocate more time to the teaching of a concept if the learner had difficulty learning it). For the non-personalized group (n = 12dyads), the instructor was provided no information about the learner. Direct instruction observations were conducted by the research assistant to confirm that the interventions were delivered as intended (see Supplementary Materials for observational data).

2.4. Procedures

The task included two blocks, each split into a resting-state phase and an interactive learning phase (Fig. 1A). The inter-block interval was approximately 1 min. During the initial resting-state phase (3 min), both participants (sitting face-to-face, 0.8 m apart) were asked to relax and to remain still. This 3-min resting phase served as the baseline.

The resting-state phase was immediately followed by the interactivelearning phase (8 min), where the learner and instructor engaged in interactive learning either in a personalized (n = 12 dyads) or nonpersonalized (n = 12 dyads) way (Instructional Personalization, Fig. 1B). For each group, the experimental procedure consisted of one of the following combinations of learning content and Instructional Strategy: (*i*) *reinforcement* with scaffolding (block 1) + *transfer* with explanation (block 2), (*ii*) *reinforcement* with explanation (block 1) + *transfer* with scaffolding (block 2). Block order was counterbalanced.

During the experiment, learners' and instructors' brain activity was recorded simultaneously via fNIRS-based hyperscanning at prefrontal and left temporoparietal regions (Fig. 1C). A digital video camera (Sony, HDR-XR100, Sony Corporation, Tokyo, Japan) was used to record the behavioral interactions between participant dyads. The acquisition of video data and fNIRS data was synchronized with a real-time audio-video cable connecting the camera to the ETG-7100 equipment. The camera recordings were used to classify (following the experiment) behavior as either scaffolding or explanatory behaviors.

2.5. Behavioral data analyses

Learners' knowledge of psychological concepts was tested immediately before the onset of the resting-state phase and after the end of the interactive-learning phase. Relevant to Reinforcement and Transfer, 8 definitions, 16 true-false items and 4 short answer questions were selected from textbooks to compose a testing bank. These items were randomly split into two halves, one for the pre-test and the other for the post-test. An additional 9 adults (mean age = 21.85 ± 1.60 years) were recruited to evaluate the difficulty level between the pre- and post-tests ($t_{(8)} = 0.01$, p = 0.99). Test reliability was estimated using the splithalf method (Cronbach's alpha = 0.81). Content validity of the test was evaluated by specialists. Two experts with at least 20 years of experience in psychology were invited to examine and provide feedback on each of the testing items. Items were revised until all experts reached consensus.

The learners had a time limitation of 20 min to finish each of the tests (Zheng et al., 2018). The performance of learners in the pre- and post-tests was scored by two separate other raters who were blind to the group assignment. Three question types (i.e., definitions, true-false items, simple answer questions) were evaluated. For each learner, inter-coder reliability was calculated by the intra-class correlation on scores for definitions and simple answer questions (ranging from 0.77 to 0.91). Rating scores were averaged across the two raters. The sum of the judgments made on all three question types (for a given learner) was considered as the index of overall learning performance [maximum score: 4 (for 4 definitions) + 16 (for 8 true-false items) + 10 (for 2 simple answer questions) = 30 points). Pre-test scores did not differ between any of the conditions (Fs < 1.60, ps > 0.17). For all subsequent analyses, learning outcomes were quantified as the difference pre-learning scores and post-learning scores. A mixed-design repeated measures ANOVA was conducted on the learning outcomes, with Instructional Personalization (personalized vs. non-personalized) as a between-subject variable and Instructional Strategy (scaffolding vs. explanation) as a within-subject variable.

2.6. fNIRS acquisition

An ETG-7100 optical topography system (Hitachi Medical Corporation, Japan) was used for brain data acquisition. The absorption of near-



Fig. 1. Experimental protocol, probe location, and brain-to-brain coupling analysis. (A) Experimental procedure. Before and after scanning, learners' knowledge of the psychological concepts was evaluated. Brain activity from the instructor and the learner were acquired simultaneously using fNIRS, in two blocks, each starting with a 3-min rest (resting-state phase/baseline), followed by the instructor teaching concepts to the learner (interactive-learning phase/ task). (B) Instructional Personalization and Instructional Strategies. Participants were randomly allocated to either personalized or non-personalized groups (Instructional Personalization). Within each instructor-learner dyad, scaffolding and explanation strategies were compared. (C) Optode probe set. The set was placed over prefrontal and left temporoparietal regions. (D) Overview of the brain-to-brain coupling analysis. Channel-wise raw time courses were extracted from both the instructor and the learner. After a battery of preprocessing, brain-tobrain coupling was estimated by Wavelet Transform Coherence between the two clean time courses. i, j, fNIRS signals of two participants of a dyad; t, time.

infrared light (two wavelengths: 695 and 830 nm) was measured with a sampling rate of 10 Hz. The oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) were obtained through the modified Beer-Lambert law. We focused our analyses on the HbO concentration, for which the signal-to-noise ratio is better than HbR (Mahmoudzadeh et al., 2013). A number of fNIRS-based hyperscanning reports have used this indicator to compute of brain-to-brain coupling (e.g., Cheng et al., 2015; Dai et al., 2018; Jiang et al., 2012, 2015; Pan et al., 2018; Tang et al., 2015).

Two optode probe sets were used to cover each participant's prefrontal and left temporoparietal regions (Fig. 1C), which have been previously associated with information exchanges between instructors and learners during interactive learning (Holper et al., 2013; Pan et al., 2018; Takeuchi et al., 2017; Zheng et al., 2018). One 3×5 optode probe set (eight emitters and seven detectors forming 22 measurement points with 3 cm optode separation) was placed over the prefrontal area. The middle optode of the lowest probe row of the patch was placed at Fpz (Fig. 1C), following the international 10-20 system (Okamoto et al., 2004). The middle probe set columns were placed along the sagittal reference curve. The other 4×4 probe set (eight emitters and eight detectors forming 24 measurement points with 3 cm optode separation) was placed over the left temporoparietal regions (reference optode was placed at P5, Fig. 1C). All probe sets were examined and adjusted to ensure consistency of the positions between the two participants of each dyad and across the dyads. The correspondence between the NIRS channels (CHs) and the measured points on the cerebral cortex was determined using a virtual registration approach (Singh et al., 2005; Tsuzuki et al., 2007; see Table S1 for detailed MNI coordinates).

2.7. fNIRS data analyses

2.7.1. Task-related brain-to-brain coupling

Data collected during the resting-state phase (3 min, served as the baseline) and the interactive-learning phase (8 min, served as the task) in each block were entered into the brain-to-brain coupling analysis

(Fig. 1D). A principal component spatial filter algorithm was used to remove systemic components such as blood pressure, respiratory and blood flow variation from the fNIRS data (Zhang et al., 2016). To remove head motion artifacts, we used a "Correlation Based Signal Improvement" approach (Cui et al., 2010).

We then employed a wavelet transform coherence (WTC) analysis to estimate brain-to-brain coupling. The WTC of signals i(t) and j(t) was defined by:

WTC(t,s) =
$$\frac{\left|\langle s^{-1}W^{ij}(t,s)\rangle\right|^2}{\left|\langle s^{-1}W^i(t,s)\rangle\right|^2\left|\langle s^{-1}W^j(t,s)\rangle\right|^2}$$

where *t* denotes the time, *s* indicates the wavelet scale, $\langle \cdot \rangle$ represents a smoothing operation in time and scale, and *W* is the continuous wavelet transform (see Grinsted et al., 2004 for details).

As a first step, we estimated whether brain-to-brain coupling was enhanced during the interactive learning task (estimated by WTC) compared to baseline. Time-averaged brain-to-brain coupling (also averaged across channels in each dyad) was compared between the resting phase (i.e. baseline session) and the interactive learning phase (i.e. task session) using a series of paired sample *t*-tests, one for each frequency band (frequency range: 0.01-1 Hz, Nozawa et al., 2016). This analysis yielded a series of *p*-values that were FDR corrected (p < 0.05). This analysis enables the identification of frequency characteristic, which help us determine the frequency of interest (FOI) for subsequent analyses.

To verify if the enhanced brain-to-brain coupling was dyad-specific, data from all 48 participants were reshuffled in a pseudo-random way so that 24 new dyads were created (e.g., time series from instructor #1 were paired with those from learner #3) (Fig. 3E). Then, the above brain-to-brain coupling analysis was performed again to obtain brain-to-brain coupling for pseudo dyads. This permutation was repeated 1,000 times. Significant levels (p < 0.05) were assessed by comparing the average brain-to-brain coupling from the original dyads with 1,000 renditions of pseudo dyads.

2.7.2. Instruction-dependent brain-to-brain coupling

We averaged brain-to-brain coupling within each identified FOI and compared all conditions. We computed an index of task-related brain-tobrain coupling by subtracting the averaged coupling during the resting phase from that during the interactive learning phase. Fisher z transformation was applied to the task-related coupling values to generate a normal distribution. The resulting values for each channel were then submitted into an Instructional Strategy (scaffolding vs. explanation) × Instructional Personalization (personalized vs. non-personalized) mixed-design ANOVA. Parallel analyses were conducted separately in each FOI. The resulting *p* values were FDR-corrected for multiple comparisons. The results yielded *F* maps for each FOI. These *F* maps were visualized using BrainNet Viewer (Xia et al., 2013).

Next, we assessed behavior-brain relationships. Pearson correlational analyses were employed to test the relationship between task-related brain-to-brain coupling from significant channels and learning outcomes.

2.7.3. Brain-to-brain coupling segmentation

Following the brain-to-brain coupling analyses, we grouped and averaged the adjacent CHs that showed significant brain-to-brain coupling as channels of interest. The time course of brain-to-brain coupling in the channels of interest was down-sampled to 1 Hz to obtain point-to-frame correspondence between the time series and video recordings (Fig. 5A&B).

Two graduate students were recruited to independently and manually code instructional behaviors in the interactive-learning phase using the video-recording data. The two coders underwent a weeklong training program by an educational expert (with 28 years of instructional experience in the field of education) to correctly identify instructional behaviors. Two types of instructional behaviors were categorized for each Instructional Strategy: for the scaffolding condition, there were (*i*) scaffolding behaviors, such as asking key questions, providing feedback and hints, prompting, simplifying problems, and (*ii*) other non-scaffolding instructional behaviors, i.e., those segments in the videos where scaffolding did not occur; for the explanation condition, there were (*i*) explanatory behaviors, such as giving detailed definitions, providing prefabricated materials, and information clarification, and (*ii*) other non-explanatory instructional behaviors, i.e., those segments in the videos where explanation did not occur.

Each 1-s (s) video fragment (from the 8 min during the interactivelearning phase) was coded as either containing scaffolding behaviors or non-scaffolding instructional behaviors in the scaffolding condition; and as either consisting of explanatory behaviors or non-explanatory instructional behaviors in the explanation condition. For all coding activities, inter-coder reliability was calculated by the intra-class correlation (Werts et al., 1974). Inter-coder reliability was 0.87 for the scaffolding behaviors (vs. non-scaffolding instructional behaviors) in the scaffolding condition, and 0.81 for the explanatory behaviors (vs. non-explanatory instructional behaviors) in the explanation condition. If there was an inconsistency, the two coders discussed it and came to an agreement.

Based on the results of the coding procedures mentioned above, we categorized the segments of brain-to-brain coupling associated with different video-coded instructional behaviors (Fig. 5A&B). We subtracted brain-to-brain coupling during the rest session (baseline) from these segments of brain-to-brain coupling to obtain the task-related coupling. Contrasts between task-related brain-to-brain coupling associated with different video-coded instructional behaviors were obtained using a series of paired-sample *t*-tests.

2.7.4. Brain-to-brain coupling prediction

Finally, we explored whether brain-to-brain coupling allowed us to predict if an instructor employed the *scaffolding* or *explanation* strategy, using a decoding analysis (Dai et al., 2018; Jiang et al., 2015). The analysis details and strategies can be described as follows.

Classification features and labels. The time-averaged brain-to-brain

coupling values at channels that exhibited significant task-related coupling (task vs. baseline; Goldstein et al., 2018) were used as classification features (see section 3.2.1; see also Supplementary Table S2 for selected features and involved channels/regions). Instructional Strategies (i.e., *scaffolding* or *explanation*) were used as class labels.

Classification algorithm. Brain-to-brain coupling features were incorporated into a logistic regression algorithm. Logistic regression is a supervised machine-learning algorithm that has been previously used to predict behavioral measures with neuroimaging data (e.g., Ryali et al., 2010). The aim of logistic regression-based machine learning is to find the best fitting model that describes the relationship between the dichotomous features of the dependent variable and independent variables (Yan et al., 2004).

Classification performance. Classification performance was assessed using the standard metric of area under the receiver operating characteristic curve (AUC). The AUC is one of the most common quantitative indexes (Faraggi and Reiser, 2002; Hanley and McNeil, 1982), which illustrates the sensitivity and specificity for the classifier output. It has been successfully used to quantify the accuracy of the prediction in many neuroimaging studies (e.g., Cohen et al., 2018; Ki et al., 2016).

A permutation test was used to determine whether the obtained AUC was significantly larger than that generated by chance. Chance level of the AUC was determined by randomly shuffling the labels (*scaffolding* or *explanation*) for the brain-to-brain coupling values. Significant levels (p < 0.05) were calculated by comparing the obtained AUC from the real labels with 10,000 renditions of randomized labels.

Additional analyses. Finally, we tested whether decoding based on brain-to-brain coupling generated a better classification of instructional behavior than decoding based on individual brain activation. The raw fNIRS data were first preprocessed following the same procedure described in section 2.7.1. Clean (task-related) signals were then converted into z-scores using the mean and the standard deviation of the signals recorded during rest (baseline). Normalized intra-brain activity values at channels of interest in both instructors and learners were extracted as classification features. The parallel decoding analyses were then repeated as described above.

3. Results

3.1. Behavioral results

A repeated measures ANOVA on learning outcomes with Instructional Strategy (Scaffolding vs. Explanation) as a within-dyad factor and Instructional Personalization (Personalized vs. Non-personalized) as a between-dyad factor revealed a main effect of Instructional Strategy ($F_{(1, 24)} = 5.10, p = 0.03, \eta_{partial}^2 = 0.19$), with the scaffolding strategy showing better learning outcomes than the explanation strategy (Fig. 2). There was no effect of Instructional Personalization on learning ($F_{(1, 24)} = 0.82$, p = 0.38) and there was no interaction between Instructional Personalization and Instructional Strategy ($F_{(1, 24)} = 0.07, p = 0.79$). In sum, learners who were taught using scaffolding retained more content from the instructional strategy.

3.2. Brain imaging results

3.2.1. Task-related brain-to-brain coupling

In a first-pass data-driven analysis, we calculated brain-to-brain coupling in all conditions across the whole sample of 24 participant dyads to test whether interactive learning (i.e., task) was associated with enhanced brain-to-brain coupling compared to the resting-state session (i.e., baseline).

In terms of frequency characteristics, brain-to-brain coupling was significantly higher during the interactive learning phase than during rest for frequencies ranging between 0.45 - 0.57 Hz and 0.17-0.27 Hz (all FDR-corrected, Fig. 3). These two ranges were then chosen as frequencies



Fig. 2. Learning outcomes in all conditions. **(A)** Group levels: in both personalized and non-personalized groups, learning outcomes for the scaffolding condition was significantly higher than the explanation condition. Learning outcomes are indexed by the change score (post-test score minus pre-test score). Error bars represent standard errors of the mean. **(B)** Corresponding graph for individual levels. *p < 0.05. **p < 0.01.

of interest (FOIs) for subsequent analyses. These FOIs are out of the range of physiological responses associated with cardiac pulsation activity (\sim 0.8–2.5 Hz) and spontaneous blood flow oscillations (i.e., Mayer

waves, ~0.1 Hz).

Regarding spatial characteristics, task-related coupling enhancement was highest in the orbitofrontal cortex, frontopolar cortex, and inferior frontal cortex at 0.45–0.57 Hz (Fig. 3C), and along superior temporal cortex, temporoparietal junction, and superior parietal lobule at 0.17–0.27 Hz (Fig. 3D). We also observed widespread brain-to-brain coupling in adjacent regions, including prefrontal, temporal, and parietal areas. These results replicate previous research showing that social interactive learning (through instruction) induces brain-to-brain coupling in high-order brain regions (Holper et al., 2013; Pan et al., 2018; Zheng et al., 2018).

A permutation analysis confirmed that the patterns of brain-to-brain coupling (higher coupling associated with interactive learning compared to rest) were specific to the interaction between real instructor-learner dyads: pseudo dyads did not show higher brain-to-brain coupling during learning than rest. Also, average brain-to-brain coupling from the original dyads significantly exceeded that from the pseudo dyads in either frequency band of interest (*ps* < 0.05, Fig. 3E). Together, our first-pass results suggest that social interactive learning induces widespread brain-to-brain coupling. This coupling is concentrated in specific frequencies and only emerges in 'real' dyads (who are actually interacting).



Fig. 3. Interactive learning evokes frequency-specific widespread brain-to-brain coupling across all conditions. **(A)** Brain-to-brain coupling associated with the instruction session and the rest session for frequencies ranging between 0.01 and 1 Hz (all participants and channels' data were averaged). Grey horizontal lines on the top indicate which frequencies show statistical differences (FDR controlled). **(B)** An FDR-corrected *P*-value map resulting from comparisons between instruction and rest (for each channel) across frequencies between 0.01 and 1 Hz. Interactive learning evokes frequency-specific widespread brain-to-brain coupling in all conditions across all dyads at 0.45–0.57 Hz (C) and 0.17–0.27 Hz (D). (E) A permutation analysis confirmed that the enhanced brain-to-brain coupling shown in (C) and (D) was dyad-specific: no significant task-related coupling was detected in pseudo-dyads in either frequency band of interest (all real dyads were shuffled, resulting in 24 new pseudo dyads; repeated 1,000 times). The figure shows the distribution of the permutated average brain-to-brain coupling enhancement. The blue lines indicate the positions of the true means of the original dyads.

3.2.2. Instruction-dependent brain-to-brain coupling

Having established that social interactive learning is associated with a significant increase in brain-to-brain coupling between instructor and learner, we next sought to determine whether such coupling enhancement was modulated by Instructional Strategy and Instructional Personalization. First, results showed a main effect of Instructional Strategy in prefrontal regions (i.e., CHs 5, 6, 10, 12) at 0.45–0.57 Hz (*Fs* > 9.50, FDR corrected *ps* < 0.05, $\eta^2 s > 0.65$). Further analyses revealed that the scaffolding strategy exhibited higher brain-to-brain coupling than the explanation strategy in all significant CHs (Fig. 4A). There were no effects of Instructional Strategy for other CHs and other frequency bands (*ps* > 0.05, FDR corrected). There was no significant main effect of Instructional Personalization in any CHs and at any frequency bands (*ps* > 0.05, FDR corrected).

We observed an interaction between Instructional Strategy and Instructional Personalization in the superior temporal cortex (i.e., CH 25) at 0.17–0.27 Hz ($F_{(1, 24)} = 13.49$, FDR corrected p < 0.05). Post hoc comparisons indicated that brain-to-brain coupling was significantly larger for the scaffolding condition than the explanation condition in the personalized group (p < 0.05), but not in the non-personalized group (p

> 0.05, Fig. 4B). No significant main effects or interactions where observed in any other CHs or frequency bands of interest (*ps* > 0.05, FDR corrected).

Average brain-to-brain coupling in prefrontal regions was positively correlated with learning outcomes in the scaffolding condition (r = 0.65, uncorrected p = 0.001; Fig. 4A, right panel) but not in the explanation condition (r = -0.24, uncorrected p = 0.27), indicating that better learning was associated with stronger brain-to-brain coupling in the scaffolding condition alone. Mirroring the ANOVA results reported above, we saw that brain-to-brain coupling in superior temporal cortex only predicted learning outcomes in the personalized scaffolding condition (r = 0.66, uncorrected p = 0.02; all other conditions: rs < -0.18, uncorrected ps > 0.27; Fig. 4B, right).

3.2.3. Brain-to-brain coupling segmentation

To investigate how instructional behaviors contributed to brain-tobrain coupling, we conducted a video coding analysis for each participant dyad. Two raters independently coded videos for scaffolding behaviors vs. non-scaffolding instructional behaviors (or explanatory behaviors vs. non-explanatory instructional behaviors). For analysis,



Fig. 4. Instruction modulates brain-to-brain coupling during social interactive learning. Central: F-test maps of brain-to-brain coupling generated based on frequencyspecific ANOVAs with Instructional Strategy and Instructional Personalization as independent variables. (A) The scaffolding condition showed higher brain-to-brain coupling in prefrontal regions than the explanation condition. Such brain-to-brain coupling predicted learning outcomes in the scaffolding condition, but not in the explanation condition (right panel). (B) The scaffolding condition also led to significantly larger brain-tobrain coupling in superior temporal cortex than the explanation condition, but only in the personalized instruction dyads. Brain-tobrain coupling predicted learning outcomes in the personalized scaffolding condition but not in other conditions (right panel). p < p0.05. Error bars indicate standard errors of the mean.





Explanatory Behaviors I Non-Explanatory Behavior

Fig. 5. Video coding analysis reveals that brain-to-brain coupling is driven by specific instructional behaviors. (**A**) Time course of brain-to-brain coupling in the learning phase for one randomly selected dyad from the scaffolding and explanation conditions. Vertical panels denote the instructional behaviors: red panels indicate scaffolding behaviors; blue ones indicate explanatory behaviors. (**B**) Examples of each instructional behavior as coded from the video frames. (**C**) Example sentences from the video coding analysis for scaffolding behaviors (asking key questions and providing hints) and explanation behaviors (definition and clarification). Box plots of task-related brain-to-brain coupling (task minus rest) across the instructional behaviors in the scaffolding and explanation conditions (**D**), in the personalized scaffolding and personalized explanation conditions (**E**), and in the non-personalized scaffolding and non-personalized explanation conditions (**F**). Crosses indicate the average brain-to-brain coupling across participant dyads. Error bars range from the min to the max value observed. *p < 0.05.

time courses of brain-to-brain coupling during the task session were first matched with video-coded instructional behaviors (Fig. 5A–C). Brain-tobrain coupling was then extracted for segments of each type of instructional behavior and averaged for each condition. Task-related coupling was then obtained by subtracting time-averaged brain-to-brain coupling during the rest session from the averaged coupling segments during the task session (Fig. 5D&E).

First, we examined whether task-related brain-to-brain coupling in prefrontal cortex detected in the scaffolding condition could be explained by scaffolding behaviors. Indeed, scaffolding behaviors induced significantly higher brain-to-brain coupling compared to the non-scaffolding instructional behaviors ($t_{(23)} = 2.72$, p = 0.01, Cohen's d = 0.78; Fig. 5D, upper panel). However, no significant differences in brain-tobrain coupling were seen between explanatory behaviors and nonexplanatory instructional behaviors in the explanation condition ($t_{(23)}$ = 1.58, p = 0.13; Fig. 5D, lower panel).

Second, we compared brain-to-brain coupling for scaffolding vs. nonscaffolding instructional behaviors to test whether scaffolding behavior indeed drove the task-related brain-to-brain coupling observed in superior temporal cortex for the personalized scaffolding condition. As expected, scaffolding behaviors exhibited larger brain-to-brain coupling than non-scaffolding instructional behaviors ($t_{(11)} = 3.19$, p = 0.01, Cohen's d = 1.18; Fig. 5E, upper panel). In contrast, just like in prefrontal cortex, brain-to-brain coupling did not differ between explanatory behaviors and non-explanatory behaviors in the personalized explanation condition ($t_{(11)} = 0.91$, p = 0.38 (Fig. 5E, lower panel). Moreover, there was no significant difference between instructional behaviors in either non-personalized scaffolding (Fig. 5F, upper panel) or non-personalized explanation conditions (Fig. 5F, lower panel, ts < 1.36, ps > 0.20).

Importantly, the effects reported here cannot be attributed to differences between conditions in terms of the mere quantity of instructional behaviors or the number of turn-takings, as evidenced by two control analyses. First, we calculated the duration ratio of instructional behaviors by quantifying the proportions of time (out of 8 min) when instructional behaviors occurred (Jiang et al., 2015; Pan et al., 2018). For example, if scaffolding behaviors occurred for a total of 3 min in an instructor-learner dyad, then the duration ratio of scaffolding behaviors should be 3/8 =0.375. Results revealed that the duration ratio was comparable between scaffolding behaviors (0.56 \pm 0.18) and non-scaffolding instructional behaviors (0.44 \pm 0.18) in the scaffolding condition ($t_{(23)} = 1.22$, p =0.25). Second, we compared the cumulative number of sequential turn-takings during interactive learning (for example, one turn-taking event could be that the instructor asks one question, followed by the answer from the learner). Results showed that the scaffolding strategy involved marginally more turn-takings than the explanation strategy $(16.67 \pm 6.54 \text{ vs.} 12.08 \pm 3.15; t_{(23)} = 2.11, p = 0.06)$. No significant correlation between the number of turn-takings and brain-to-brain coupling was detected (rs < 0.42, ps > 0.18).

In sum, brain-to-brain coupling could be explained by dynamic scaffolding behavior implemented in the instructor-learner interaction. Our complementary analyses ruled out frequency of instructional behaviors or turn-taking behavior as possible contributors to the observed brain-tobrain coupling effects.

3.2.4. Brain-to-brain coupling prediction

Finally, we tested the extent to which one can identify the Instructional Strategy employed by an instructor (i.e., *scaffolding* or *explanation*) based on task-related brain-to-brain coupling alone. Brain-to-brain coupling was extracted from all channel combinations that showed significantly higher brain-to-brain coupling for task vs. baseline to train the classifiers (see Supplementary Table S2 for selected channels and involved regions; see also results for prediction across all the channels and with channel combination that showed the best performance in Table S2 and Fig. S1). The classifier successfully distinguished instructors who employed the *scaffolding* or *explanation* strategy with an Area Under the Curve (AUC) of 0.90, i.e., significantly exceeding chance (p < 0.0001, Fig. 6A). The decoding analysis based on task-related brain-to-brain coupling further showed that the classifier was able to distinguish instructors who employed the *scaffolding* or *explanation* strategy for the personalized condition (AUC = 0.84; p = 0.005, Fig. 6B), but not in the non-personalized condition (AUC = 0.66; p = 0.17, Fig. 6C).

Importantly, when using individual brain activation from either instructors' or learners' as classification features, classification performance to discriminate between the *scaffolding* and *explanation* strategies was low (AUCs <0.66, *ps* > 0.05). The decoding analysis based on the individual brain activation was also insufficient to distinguish the *scaffolding* and *explanation* strategies for both personalized (AUCs <0.57, *ps* > 0.35) and non-personalized conditions (AUCs <0.56, *ps* > 0.20).

Taken together, these results indicate that brain-to-brain coupling, as a novel yet promising neural-classification feature (Jiang et al., 2015), was suitable for decoding instructional strategy with a reasonable classification performance, particularly when the instruction was tailored to the learner (i.e., personalized vs. non-personalized). Brain-to-brain coupling further served as a better classification feature compared to individual brain activation during instructor-learner interactions.

4. Discussion

This study investigated how verbal instruction modulates interactive learning using an fNIRS-based hyperscanning approach, which allowed us to record brain activity from both instructors and learners during an instruction exchange. Twenty-four instructor-learner dyads performed a conceptual learning task in a naturalistic instruction situation where a well-trained instructor taught a learner a set of psychological concepts. We found that interactive learning induced task-related brain-to-brain coupling. Brain-to-brain coupling co-varied with learners' subsequent learning outcomes and was significantly higher when instructors employed scaffolding tactics (e.g., asking key questions and hinting) than when they used an explanation-based teaching approach. This brain-tobrain coupling associated with scaffolding was especially prominent if instructors were informed of the learner's knowledge level in advance. Finally, different instructional strategies could successfully be decoded based on brain-to-brain coupling alone, but, crucially, not based on individual brain activation.

Importantly, our findings were specific to the interacting instructorlearner dyads (control analysis #1) and they did not reflect the mere quantity of instructional behaviors (control analysis #2), nor the amount of turn-takings between instructor and learner (control analysis #3).

4.1. Using two brains to study learning and instruction

Educators have long debated which method of instruction is most conducive to learning. Several researchers have sought an answer to this question by studying learners' neural activity during both information encoding and retrieval. However, previous studies have primarily focused on isolated individuals (e.g., Hartstra et al., 2011; Olsson and Phelps, 2007; Ruge and Wolfensteller, 2009). This poses a limitation to obtaining full insight into the learner process, especially for instruction-based learning, which relies on the dynamic instructional interaction between instructor and learner.

As already touched upon in the Introduction, our work supports the development of a "second-person neuroscience" (Redcay and Schilbach, 2019; Schilbach et al., 2013) and aligns with ongoing efforts to study the human brain within its social context, which in recent years has rendered a rich set of findings pertaining to the relationship between social cognition (also psychological engagement) and interpersonal synchrony: eye-to-eye (Barišic et al., 2013; Pfeiffer et al., 2013; Rogers et al., 2018), body-to-body (Baimel et al., 2018; Sharon-David et al., 2019), and brain-to-brain (including work from our own group, such as Dikker et al., 2017; Pan et al., 2018).

In this study, we aimed to quantify brain-to-brain coupling between the instructor and the learner in relation to learning. It has been proposed



Fig. 6. Decoding performance. The receiver operating characteristic (ROC) curve for classification distinguishing the *scaffolding* or *explanation* strategy in general (**A**), in the personalized (**B**), and non-personalized conditions (**C**). Area under the curve (AUC) was calculated. Significant levels were calculated by comparing the correct AUC from the real labels with 10,000 renditions of randomized labels.

that such neural alignment facilitates the matching of the temporal structure of inputs and optimizes the learning process (e.g., Leong et al., 2017; Pan et al., 2018). In line with these proposals, our findings suggest that brain-to-brain coupling is pedagogically relevant. First, brain-to-brain coupling was correlated with learning outcomes, hinting at its functional significance. Second, brain-to-brain coupling was successfully used to decode instructional approaches.

To our knowledge, we are the first to use activity from two brains as opposed to one to decode instructional strategies. We found that brain-tobrain coupling served as a better neural-classification feature in contrast with individual brain activity. This finding was in line with recent advances; for example, a recent study found that brain-to-brain coupling yielded higher predictive power for learning outcomes compared to single-brain measures (Davidesco et al., 2019). A possible explanation for this is that non-neuronal artifacts are systematic in individual brain activity (Zhang et al., 2016), while such artifacts are not consistent across brains. Indeed, brain-to-brain coupling has been reported to have higher signal-to-noise than single-brain measures (Parkinson et al., 2018). Moreover, measuring coupling across brains can provide complementary information that cannot be revealed by conventional individual brain measures (Balconi et al., 2017; Simony et al., 2016). Compared to single-brain activity, brain-to-brain coupling could be more sensitive when tracking ongoing social interactions because it considers the neural dynamics from all interacting agents simultaneously. In sum, there are several benefits of recording activity from two brains (versus one brain) to study learning and instruction.

4.2. The role of prefrontal and temporal cortices in brain-to-brain coupling

The modulatory effects of instruction on brain-to-brain coupling were concentrated in prefrontal and superior temporal cortices. This is in line with prior fNIRS-based hyperscanning studies that found that brain-tobrain coupling in prefrontal cortices (PFC; Holper et al., 2013; Pan et al., 2018; Takeuchi et al., 2017) and temporoparietal regions (Zheng et al., 2018) predicted learning outcomes following instruction. PFC has been associated with a wide range of human cognitive functions. Specific to hyperscanning, PFC has been implicated in cooperation (Cheng et al., 2015), competition (Liu et al., 2015), and emotion regulation (Reindl et al., 2018). In this study, the scaffolding process might require constant collaborative interaction between instructor and learner, a process for which prefrontal areas are heavily recruited.

Superior temporal cortex (STC), like PFC, has been associated with many cognitive functions that are relevant for learning, and social cognition more broadly. For example, STC is a key area for theory of mind or mentalizing (Baker et al., 2016), and has been implicated in social perception and action observation (Thompson and Parasuraman, 2012). While the exact role of STC in brain-to-brain coupling during learning cannot be inferred based on the present findings, it is possible that brain-to-brain coupling in this area reflects the shared intentionality or mental state between instructor and learner, or a process whereby instructors need to infer the understanding of the learner such that instruction can be adapted or personalized accordingly (Zheng et al., 2018).

Another possibility is that the correlation between brain-to-brain synchrony and learning outcomes in STC and PFC can be accounted for in terms of the ability of the instructor and learner to predict each other's mental states and utterances throughout the interaction. Prior fMRI studies investigating speaker-listener brain-to-brain coupling found that brain activity was more correlated between speakers and listeners in STC for more predictable speech (Dikker et al., 2014) and PFC brain-to-brain coupling has been associated with information retention (Stephens et al., 2010). Both PFC and STC have been found crucial for temporal predictive encoding and integration of behavior (Amoruso et al., 2018; Yang et al., 2015) and recent models attribute a large role to predictive coding in explaining interpersonal alignment at both the neural and the behavioral level (Garrod and Pickering, 2009; Shamay-Tsoory et al., 2019).

4.3. Linking brain imaging findings to pedagogical practice

As the Chinese educator Confucius suggested, appropriate instruction matters during instructor-learner interactive learning (Chen, 2007). Several instructional approaches have been proposed aiming at improving pedagogy. These approaches include explanation-based and constructivism-based instructions, both of which have been shown demonstrated to support learning (Chi, 2013).

As laid out in the introduction, an explanation-based approach puts emphasis on information clarification and aims at providing prefabricated explanatory information to the learner. Explanation is a conventional strategy used in classroom instruction (Leinhardt and Steele, 2005), human tutoring (Chi et al., 2004), cooperative learning (Webb et al., 2006), and skill acquisition (Renkl et al., 2007). In a constructivism-based approach, in contrast, the instructor is encouraged to provide support (i.e., scaffolding) tailored to the needs of the learner (Kleickmann et al., 2016). In this framework, instructional modulation of learning arises from exogenous constructivist instruction (Jumaat and Tasir, 2016). Arguably, our findings favor a constructivism-based model: (*i*) brain-to-brain coupling during interactive learning was greater when the instructor used a scaffolding strategy than when they used an explanation-based strategy; (*ii*) such coupling was primarily driven by moments during the instructor-learner interaction involving scaffolding behaviors, a central feature of a constructivist approach to instruction-based learning. Together, our study contributes evidence suggesting that, in real-life classroom teaching, constructive behaviors such as asking key questions and providing hints, promote information exchange and knowledge transfer between instructor-learner dyads and, consequently, learning outcomes. This interactive process, which is associated with an increase in instructor-learner coupling, is lacking when learners passively receive instructional explanations from instructors.

It is important to note that our results do not warrant the conclusion that explanation-based instruction is completely not useful: this would go against decades of research showing that people do learn from explanations (Chi et al., 2004; Leinhardt and Steele, 2005; Renkl et al., 2007; Webb et al., 2006). Future studies combining the present two-brain approach with modelling techniques (e.g., a multilevel Bayesian framework, Bolis and Schilbach, 2017) may help further elucidate the (computational and neural) mechanisms that distinguish scaffolding and explanation strategies during instructor-learner interactions. Last but not the least, as instructor-learner relationship is a strong predictor of learning outcomes (Bevilacqua et al., 2019), future investigations should consider more factors in learning interactions, such as interpersonal similarity (Liviatan et al., 2008), interpersonal mimicry (Yun et al., 2012), personality traits and closeness (Dikker et al., 2017), to name a few.

4.4. Limitations

This study has a number of limitations. First, spatial resolution and brain depth is restricted in fNIRS, limiting measurements to (specific areas of) the cortical surface (cf. Pan et al., 2019). Structures such as ventromedial prefrontal cortex (VMPFC) and the ventral striatum (relevant for motivation and reward systems), which reputedly play a role in learning activities (Costa et al., 2016; Dunsmoor et al., 2019), are thus not detectable. One way to overcome this limitation is by conducting concurrent fMRI-fNIRS. Second, due to limited number of fNIRS channels, our optode probe set only covered prefrontal and left temporo-parietal regions, leaving other regions unexplored. Importantly, this does not cover the right temporo-parietal junction (TPJ), which has previously been reported as highly relevant for social interactions (e.g., Bilek et al., 2015; Zillekens et al., 2019). The role of this brain area should be examined in future studies. Finally, the power of our statistical tests was possibly constrained by sample size. In our experiment, no statistical methods were used to predetermine sample size, but our sample size is similar to those reported in previous hyperscanning studies using the instructor-learner interaction paradigm (e.g., Bevilacqua et al., 2019; Pan et al., 2018; Takeuchi et al., 2017) as well as studies conducting classification analyses based on brain-to-brain coupling data (e.g., Dai et al., 2018; Jiang et al., 2012). Future replications are encouraged to consolidate the current findings by increasing both the sample size and number of testing block.

4.5. Conclusions

Recording brain activity from multiple participants simultaneously in ecologically valid settings is a nascent but promising field of research. We investigated interactive learning using fNIRS hyperscanning in a naturalistic learning situation, and found that verbal instruction modulates learning via brain-to-brain coupling between instructors and learners, which was driven by dynamic scaffolding representations. Importantly, brain-to-brain coupling was effective to discriminate between different instructional approaches and predict learning outcomes. Together, our findings suggest that brain-to-brain coupling may be a pedagogically informative implicit measure that tracks learning throughout ongoing dynamic instructor-learner interactions.

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Declaration of competing interest

The authors declare no competing financial interests.

CRediT authorship contribution statement

Yafeng Pan: Writing - original draft, Writing - review & editing, Formal analysis, Investigation, Methodology, Data curation, Conceptualization. Suzanne Dikker: Writing - review & editing, Methodology. Pavel Goldstein: Writing - review & editing, Methodology. Yi Hu: Writing - review & editing, Funding acquisition.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuroimage.2020.116657.

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Comments to the Author Thank you for this revised manuscript. I am now happy to recommend the paper for publication.

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1 Abstract

Using a radial frequency discrimination task that has not been tested in many previous 2 3 studies, we examined the dependence of the pattern radius (4 to 16 deg) on the radial frequency thresholds of two different types of concentric radial frequency (RF) 4 patterns: constant circular contour frequency (CCF) RF patterns with different radii, 5 6 which have the constant physical length of modulation cycle in external real-world space, and constant radial frequency magnified RF patterns with different radii, which 7 8 have the constant cortical length of modulation cycles. These two types RF patterns 9 used as the reference stimuli had an equal maximum orientation difference from 10 circularity regardless of change in radius. 11 The discrimination threshold expressed by the frequency ratio between RF patterns of 12 different frequencies vs radius functions for the constant CCF RF patterns indicated 13 different functional forms dependent on the modulation amplitude of the RF patterns. 14 The thresholds increased with increasing pattern radius for small modulation amplitude RF patterns but were relatively flattened for large amplitude RF patterns. This 15 dependence was ascribed to the eccentricity effect wherein the deformation thresholds 16 17 for discriminating the RF pattern from a circle increase with increasing stimulus

18 eccentricity (Feng et al. in review).

5	Keywords: concentric radial frequency pattern; eccentricity effect; discriminability;
4	the eccentricity effect observed for the constant CCF patterns.
3	(frequency ratio) were similar at all eccentricities. Cortical magnification neutralized
2	also flattened for different modulation amplitudes and frequencies. The thresholds
1	The discrimination thresholds vs radius functions for the magnified RF patterns were

6 frequency ratio; orientation ratio; retinocortical mapping; discrimination task.

1 Introduction

2	Radial frequency (RF) patterns, which were introduced by Wilkinson, Wilson, and
3	Habak (1998), have frequently been used to investigate aspects of shape processing.
4	The simple mathematical definition of RF patterns has made RF patterns a popular
5	stimulus in psychophysical, physiological, and imaging studies (Wilkinson et al., 2000;
6	Loffler, 2008; Loffler, 2015; Salmela et al., 2016). However, Wilkinson et al. (1998)
7	explained the mathematical limitation of RF patterns and stressed their differences from
8	Fourier shape descriptors, which can in principle be used to create any kind of closed
9	two-dimensional shapes. Recently, Schmidtmann and Fruend (2019) demonstrated that
10	compound RF patterns can represent only a very small subset of natural and synthetic
11	shapes, but the RF patterns are not suited as universal shape descriptors utilized by the
12	visual system. Schmidtmann and Fruend (2019) also noted that it is important to keep
13	in mind that studies of RF patterns implicitly restrict them to only certain ranges of
14	perceptually meaningful dimensions. Despite this limitation, there remains the
15	possibility that accumulating structural properties of the visual performance of RF
16	patterns further by using a wider range of stimulus condition and a different visual task
17	and by exploring a possible model may open a new perspective and lead to deep insight
18	into the shape encoding mechanism.

19 Here, we provide an additional test on the discrimination performance of RF patterns

1 presented in the peripheral visual field. We asked three questions regarding the visual 2 performance to concentric RF patterns with a radius that varied from 4 to 16 deg, using 3 a frequency discrimination task: What are the most important factors to determine the discrimination between different RF patterns? How does the discrimination 4 performance vary with eccentricity? How can spatial scaling (the retinocortical 5 6 transformation) account for the eccentric properties of the discrimination performance? RF patterns are constructed by applying a radial sinusoidal modulation to the radius r₀ 7 8 such that the radius of the deformed pattern at polar angle θ in radians is:

9
$$r = r_0(1 + A\cos(\omega\theta + \varphi))$$
 (1)

10 where r_0 is the mean radius, A is the radial modulation amplitude, and ω is the radial 11 frequency. The primary parameters of visual performance for RF patterns are 12 modulation amplitude (A) on the radial coordinate and radial frequency (ω) on the 13 angular coordinate. These two parameters are in an orthogonal relationship with each other. They can be varied independently. However, they cannot affect the salience of 14 the modulation independently. Properties such as local curvature and the maximum 15 16 local orientation difference from circular vary with both of these parameters. Most 17 previous studies have used a deformation threshold task in which the modulation 18 amplitude threshold to discriminate the RF pattern from a circular pattern is measured by manipulating the modulation amplitude. In previous studies, the radial frequency of 19

1	RF patterns was used as an important parameter that affects visual performance.
2	Surprisingly, to our knowledge, radial frequency discrimination tasks, in which the
3	discrimination threshold to detect the difference in the frequency between two RF
4	patterns is measured by manipulating the radial frequency of the RF patterns, has rarely
5	been studied; some exceptions, however, include psychophysical studies that have used
6	radial frequency identification tasks (Wilkinson et al., 1998; Poirier and Wilson, 2006;
7	Bell et al., 2007; Dickinson et al., 2013). The frequency discrimination threshold task
8	used in this study may plausibly shed new light on the aspect of the visual performance
9	of RF patterns. The radial frequency discrimination task may be useful to examine the
10	sensitivity to changes in the angular coordinate of RF patterns and the frequency
11	selectivity in the processing of RF patterns.
12	Achtman, Hess and Wang (2000), Zolubak and Garcia-Suarez (2017, 2018), and
13	Zolubak, Schmidtmann and Garcia-Suarez (2018) reported that the performance of RF
14	patterns presented in the peripheral retinal location decreased, and Achtman et al.
15	(2000) showed that the eccentricity effect could be neutralized by scaling with respect
16	to cortical magnification factors. In this last study, the researchers used a deformation
17	task. In the present study, we tested the eccentricity effect for magnified and
18	nonmagnified concentric presentations of RF patterns using the radial frequency
19	discrimination task.

1	In the present study, using constant circular contour frequency (CCF) patterns with
2	different radii, which have the constant physical length of modulation cycle in external
3	real-world space, and constant radial frequency magnified RF patterns with different
4	radii, which have the constant cortical length of modulation cycles, we examined the
5	effect of the RF pattern radius (between 4 to 16 deg) on radial frequency discrimination
6	thresholds. As a consequence, we found that the discrimination thresholds between
7	different frequency-magnified patterns were determined by the frequency ratio of the
8	two patterns, regardless of different pattern radii and reference frequencies.

1 General Methods

2 **Participants**

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3 The participants included one of the authors and four healthy students (three males, 27.7±3.8 years old). All participants had normal vision or corrected-to-normal vision 4 and provided written informed consent for the procedure, which was previously 5 6 approved by the ethics committee of Okayama University and was organized to ensure conformity to the Declaration of Helsinki. 7 8 Apparatus 9 MATLAB (MathWorks, Inc.) and Psychophysics Toolbox (Brainard, 1997), which provides high-level access to the C-language Video Toolbox (Pelli, 1997), were used to 10 11 generate the custom stimuli used in this experiment. The program was run on a 12 ThinkPad T540p notebook (Lenovo). Stimuli were presented on a SHARP-PN455 13 (SHARP) display with a 60 Hz frame rate, 8-bit colors and 1920×1080 pixels. The

via calibration through a KONICA-MINOLTA CS-100A (Konica Minolta Japan, Inc.)

gamma nonlinearity of the screen was corrected using a look-up table that was obtained

spectroradiometer. The color of the stimuli was set to CIE 1931, x = 0.34, y = 0.33, and the mean luminance of the screen was 175 cd/m². The stimulus luminance was modulated around a mean luminance of 175 cd/m² about each eccentricity, while the

19 remainder of the screen was maintained at the mean luminance.

1	The participants viewed the display monocularly under dim room illumination at a
2	distance of 80 cm. Each display subtended 63.3 deg horizontally and 38.2 deg vertically.
3	The participants were instructed to sit on a chair, put their chin on a chin-stand to ensure
4	that the head did not move and maintained the distance from the screen, and keep their
5	fixation at the fixation point presented in the center of the display during the
6	presentation of the target stimuli.
7	Base Stimuli
8	The base pattern used in this study was a circular contour with a cross-sectional
9	luminance profile defined by a radial fourth derivative of a Gaussian (D4). The pattern
10	used in this study was the same as that used by Wilkinson et al. (1998).
11	The equation for the circle is
12	$D4(r) = C \times \exp\left(-\frac{(r-r_0)^2}{\sigma^2}\right) \times \left(1 - 4\frac{(r-r_0)^2}{\sigma^2} + \frac{4}{3}\frac{(r-r_0)^2}{\sigma^2}\right) $ (2)
13	where C is the pattern contrast, which was 100% through all current experiments; r_0 is
14	the mean radius of the stimulus, the center of which was located at the fixation point;
15	and σ determines the thickness of the cross-sectional profile.
16	The base circle was deformed by applying a radial sinusoidal modulation to the radius
17	r_0 in equation (2) such that the radius of the deformed pattern at polar angle θ in radians
18	was as shown in equation (1).

The angular phase of the pattern is determined by φ. The radial modulation amplitude
 (A) was not permitted to exceed 1.0, and the radial frequency was always an integer
 value.

4 **Peripheral sensitivity for radial frequency discrimination**

Schmidtmann, Logan, Keendy, Gordon, and Loffler (2015) tested the hypothesis of 5 6 enhanced sensitivity to a range of stimuli within the lower visual field by measuring discrimination sensitivity for orientation, curvature, shape (radial frequency patterns), 7 8 and faces at various para-central locations and eccentricities. Peripheral sensitivity was 9 isotropic for orientation and curvature. By contrast, observers were significantly better 10 at discriminating shapes throughout the lower visual field compared to elsewhere. For 11 faces, peak sensitivity was found in the lefty visual field. Note here that the visual field 12 preference was observed for small visual stimuli. To our knowledge, no study for large 13 RF stimuli such as our experimental stimuli (8~32 diameter stimuli) has been examined. No one knows whether the low field preference is also observed or not for our large RF 14 stimuli. This problem is interesting, but beyond the scope of the present study. 15 16 Our radial frequency discrimination which is closely related to orientation or curvature 17 discrimination is isotropic in sensitivity in the peripheral visual field. Procedure 18

19 The thresholds to discriminate the target radial frequency from the reference frequency

1	were measured using a three-alternative forced-choice procedure and the method of
2	constant stimulus. In the frequency discrimination experiments, there were seven radial
3	frequencies for the target stimuli with constant modulation amplitude: one frequency
4	was the same as the reference frequency (for example 9 cycles/360 deg), three
5	frequencies were higher (10, 11 and 13 cycles/360 deg for the reference frequency of 9
6	cycles/360 deg), and three frequencies were lower (6, 7 and 8 cycles/360 deg). They
7	were arranged at nearly equal intervals on a logarithmic scale. When the target and
8	reference have the same radial frequency, the participants may feel substantial difficulty
9	in making a binary decision, e.g., "target has a higher radial frequency than the
10	reference", or "target has a lower radial frequency than the reference". To circumvent
11	this problem, we used the three-alternative forced-choice procedure rather than the two-
12	alternative forced-choice procedure used by the majority of previous RF pattern
13	research, in which the participants may select a third choice "target and reference have
14	the same radial frequency". Additionally, we used the three-alternative forced-choice
15	procedure rather than the two forced-choice procedure because the latter is known to
16	present with a potential difficulty: at low signal intensities (small differences in
17	frequency between target and reference), the participant (particularly a naïve observer)
18	is often truly uncertain about the correct answer from a two-alternative forced-choice
19	task. Being forced to make a choice even when one does not have the slightest idea

1	regarding which response is correct may introduce an uncomfortable aspect to this task.
2	This may be particularly important in situations in which the participant is confronted
3	for the first time with this task or where it is infeasible to dispel the reluctance of the
4	participants to act randomly because it would require too much explanation and might
5	reduce the confidence of the participants in the seriousness of the investigation
6	(Kaernbach, 2001). The feasibility of using a "guess-button" in addition to the
7	conventional response keys defined in 2FAC tasks has also been proved to yield a more
8	precise result (García-Pérez, 2010).
9	Participants were presented with a five-minute dark adaptation to the dim room and a
10	three-minute light adaptation to the mean luminance of the display. This procedure was
11	performed to acclimate the participant's eyes to quickly adapt to the mean luminance
12	of the experimental display. Each trial subsequently consisted of two 200 ms stimulus
13	presentation intervals with a 300 ms ISI and a response interval; one presentation
14	interval contained the reference stimulus, while the other presentation interval
15	contained one of the target stimuli. The presentation order of the reference and target
16	were randomized within a session. The phase of the stimuli was varied randomly
17	between trials. This random-phase setting rendered it impossible for the subjects to
18	predict the exact locations at which the maximum and minimum radial deviations
19	would occur. The participants were instructed to indicate whether, compared to the first

1	stimulus (S1), the frequency of the second stimulus (S2) was higher, lower or same
2	using one of three buttons: one button for the S2 frequency being higher than the S1
3	frequency, another button for the S2 frequency being lower than the S1 frequency, and
4	a third button for S2 and S1 having the same frequency. (Fig. 1). With the participant's
5	self-paced starting signal, the next session began. Within a session, the seven radial
6	frequency targets were randomly presented, with each presented 10 times, while the
7	other stimulus parameters of the target and the reference were held constant. The four
8	stimulus radii were randomly presented across sessions.
9	Fig. 1
10	Analysis
11	We used a three-alternative forced-choice procedure. The responses of the participants
12	were composed of "higher", "lower" and "same" responses. Based on the "higher" and
13	"lower" responses, we obtained the following logistic curve equation:
14	$y = \left(1 + e^{\alpha + \beta x}\right)^{-1} \tag{3}$
15	where the responses of the participants are expressed from 0 to 100% on the ordinate.
16	The abscissa corresponds to the target radial frequency from 6 cycles/360 deg to 13
17	cycles/360 deg, and 9 cycles/360 deg is the reference radial frequency (ω_R). From the
18	logistic curve, we obtained two key points on the abscissa: ω_{TH} , the frequency where
1 participants achieved 25% on the ordinate, as shown in Fig. 2.

2

Fig. 2

We calculated the radial frequency discrimination thresholds by using the followingequation:

5 Discrimination thresholds
$$=\frac{\ln(\omega_{TH}) - \ln(\omega_{TL})}{2} = ln\left(\left(\frac{\omega_{TH}}{\omega_{TL}}\right)^{\frac{1}{2}}\right)$$
 (4)

6 Dickinson, McGinty, Webster and Badcock (2012) showed that the quantity that was equated at thresholds for detection of modulation on RF patterns of different 7 frequencies but with the same number of cycles of modulation was the maximum 8 9 angular deviation from circularity. This was for patterns with relatively low frequencies 10 of modulation that have been shown to exhibit integration of information across cycles, 11 but not for patterns with higher frequency. It was consistent with the results of other 12 study (Loffler et al., 2003). It is suggested that an important cue for the discrimination 13 between RF different stimuli, regardless of information integration, may be the maximum angular deviation from circularity. 14

The maximum angular deviation (orientation difference) between an RF and a circle occurs where an RF and a circle intersect each other and given by the following equation (Dickinson et al., 2012; Schmidtmann and Kingdom, 2017).

18 Maximum orientation differences $(tan(\alpha)) = A\omega$ (5)

19 Where α represents the angle between the tangential directions of an RF pattern and the

1	circle at the crossing point. A and ω represent the modulation amplitude and the radial
2	frequency of the RF pattern, respectively. The maximum orientation difference is
3	abbreviated as MOD.
4	Thus, the ratio of MODs between two RF patterns of equal radius and modulation with
5	ω_1 and ω_2 is equal to the radial frequency ratio of the two patterns, implying that the
6	ratio of MODs may be a critical cue to discriminate two different RF patterns as well.
7	The discrimination thresholds in the equation (4) is expressed also by the ratio of MODs
8	of the two patterns.

1 Experiment 1

Experimental stimuli: Constant circular contour frequency (CCF) RF pattern
 stimuli

The CCF is defined by the number of radial cycles per deg of unmodulated contour 4 length measured in deg of viewing angle. This is an important factor in determining the 5 6 deformation thresholds of RF patterns because regardless of the RF or radius, the radial 7 deformation thresholds are closely matched across the entire range of circular contour 8 frequencies, suggesting that the patterns with the same circular contour frequency 9 should have the same radial deformation threshold (Jeffrey et al., 2002). 10 To examine the dependence of the radial frequency discrimination thresholds on the 11 radius (eccentricity), we used the RF reference patterns with constant CCF (r_0/ω = 12 constant) and constant absolute modulation amplitude ($Ar_0 = constant$) for changes in 13 radius (4 ~ 16 deg). The constant CCF RF patterns were created by covarying the radius 14 and radial frequency such that they have an identical CCF regardless of the change in the radius. Fig. 3 (a) shows a schematic of an example of the constant CCF RF pair. 15 16 The two patterns with different radii and RFs have the same CCF. Moreover, the σ of 17 the two patterns remains constant. These two patterns' cycles of modulation travel the

18 same length in physical space. We used three series of constant CCF (CCF = 0.358

19 cycles/cl-degree) patterns with different radii (4, 8, 12 and 16 deg) but the same

1	thickness ($\sigma = 1$ deg) as the reference stimuli. Fig. 3 (b) shows the experimental
2	reference stimuli used in this experiment.
3	The absolute modulations (r_0A) of the reference RF patterns were held constant (0.12,
4	0.24, 0.48 deg) within a session but were different across sessions. The product of r_0A
5	and the contour length reflects the size of a single cycle of the RF patterns. This
6	indicates that the size of the stimuli was held constant within a session.
7	Fig. 3
8	Results
9	In experiment 1, the discrimination thresholds were measured as a function of the radius
10	over a range from 4 to 16 deg (14 deg instead of 16 deg when $r_0A = 0.12$ deg, because
11	of the impossibility of measurement otherwise) for the five participants. In Fig. 4, the
12	mean of the discrimination thresholds for the five participants is plotted against the
13	radius. The thresholds vs. radius functions were strongly dependent on the stimulus
14	conditions (r ₀ A) of the target and reference stimuli. The thresholds substantially
15	increased with increasing radius for the condition $r_0A = 0.12$ deg, i.e., the small stimulus
16	size and slightly increased for the condition $r_0A = 0.24$ deg, while they remained
17	constant for the condition $r_0A = 0.48$ deg, i.e., the large stimulus size. In this instance,
18	the increase in the threshold implied a decrease in the discrimination performance,
19	which indicates a radius effect of the RF patterns. The radius effect was observed for

1	the condition $r_0A = 0.12$ deg, but not for the condition $r_0A = 0.48$ deg. To test for
2	significant differences in the group data, we used three one-way ANOVA. Based on the
3	results, a main effect for the condition $r_0A = 0.12$ deg, F (3, 12) = 9.627, p < 0.05; and
4	the condition $r_0A = 0.24$ deg, F (3, 12) = 23.606, p < 0.05 has been found. However, no
5	main effect for the condition $r_0A = 0.48 \text{ deg}$, F (3, 12) = 0.197, p = 0.77 has been found.
6	Fig. 4
7	Discussion
8	As shown in Fig. 4, the discrimination thresholds between different-frequency RF
9	patterns vs radius functions for the constant CCF RF patterns indicated different
10	functional forms dependent on the modulation amplitude of the RF patterns. The
11	thresholds showed an increasing functional form for small modulation amplitude RF
12	patterns ($r_0A = 0.12$ and 0.24 deg) but a flattened function for large amplitude RF
13	patterns ($r_0A = 0.48 \text{ deg}$).
14	The effect of the pattern contrast (100 %)
15	We used the pattern contrast of 100 % through all present experiments.
16	The relationship between the physical variables and radial frequency discriminations
17	does not always involve a simple one-to-one mapping between the two variables. The
18	other stimulus characteristics which are likely to modify the relationship include the
19	contrast and spatial frequency of the base stimulus. We used the stimulus contrast of

1	100 % and the peak spatial frequency of 0.45 c/deg in the Experiment 1. The perceived
2	contrast of the Gabor patches decreases with increasing eccentricity (0 ~ 13 deg) even
3	partially compensating by scaling stimulus size in the periphery (Vanston et al., 2018).
4	The shape discrimination threshold of RF pattern of 4 cycles/360 deg from a circle
5	decreases with increasing stimulus contrast from about $20 \sim 100$ % for the condition of
6	spatial frequency = 1 cpd and radius = 2.5 deg, but not for the condition of spatial
7	frequency $5 \sim 10$ cpd and radius = 2.5 or 1 deg) (Ivanov and Mullen, 2012). The shape
8	discrimination threshold of RF pattern decreases with increasing stimulus contrast from
9	12.5 ~ 100% for the condition of radial frequency of 5 ~ 12 cycles, but not for the
10	condition of redial frequency of $2 \sim 4$ cycles/360 deg (Wilkinson et al.,1998). This
11	implies that the reduction in the perceived contrast with increasing eccentricity may
12	result in increase of discrimination thresholds observed at eccentricity of 16 deg for
13	the condition of $r_0A = 0.12$ and 0.24 deg in Fig. 4. However only the reduction in the
14	perceived contrast with increasing eccentricity cannot explain our result indicating the
15	constant discrimination thresholds for the condition of $r_0A = 0.48$ deg regardless of
16	eccentricity change.

1 Pattern radius effects of radial frequency discrimination thresholds for constant

2 CCF RF patterns

3	The path of the RF patterns is less salient as the radius of the RF pattern increases. It
4	might be the case that for the patterns with $r_0A = 0.12$ (and to a lesser extent 0.24) the
5	larger receptive fields (lower spatial frequency preference) span cycles of modulation
6	and smooth the percept of the path. This might result in an increase in the threshold.
7	It is well established that the performance of visual discrimination, such as the
8	frequency, orientation, temporal frequency, vernier acuity, blur, displacement and
9	separation, is dependent on the signal strength, such as the contrast and size of a
10	stimulus, with performance improving as the signal increases (Bowne, 1990; Reisbeck
11	and Gegenfurtner,1998; Skottun et al., 1987; Webster et al.,1990; Westheimer et al.,
12	1999; Marechal and Shapley, 2004).
13	If radial frequency discrimination is processed by the orientation selective mechanism,
14	our results may show common behavior with previous studies concerning orientation
15	discrimination performance.
16	Specifically, in experiments where the stimuli (grating, Gabor element) were small,
17	increasing the contrast lowered the orientation threshold (Regan and Beverley, 1985;
18	Skottun et al. 1987; Reisbeck and Gegenfurtner, 1998; Mcllhagga and Mullen, 1996),

1	whereas in the experiments when the stimuli were large, orientation discrimination
2	thresholds were fairly contrast independent (Bownw, 1990; Skottun et al, 1987).
3	In the experiments performed by manipulating stimulus size, threshold estimates were
4	lowest (acuity highest) for the largest size patch and increased as the stimulus size was
5	reduced (Henrie and Shapley, 2001); the differential thresholds or JNDs in the
6	orientation of a line stimulus at a given reference orientation (horizontal and oblique)
7	decreased up to a stimulus length of 1 deg; over 1 deg, discrimination was not improved
8	for the oblique orientation while for the horizontal orientation it improved gradually up
9	to a length of 8 deg (Orban et al., 1984). Mareschal and Shapley (2004), by varying
10	systematically both contrast and size of a circular patch of grating, found that
11	orientation discrimination thresholds decreased as contrast was increased for stimuli
12	roughly smaller than 0.5 \sim 0.8 deg in diameter, and as size was increased for stimuli
13	with less than 4 \sim 20 % grating contrast. The thresholds were saturated at constant level
14	for larger stimuli than 1 deg in diameter and with greater than 20 % contrast.
15	The general finding was that as the stimulus signals (contrast and/or size) increased,
16	the orientation discrimination thresholds for grating patches decreased rapidly at first,
17	then gradually and finally asymptotically approached a saturated level.
18	We asked whether the above context concerning the signal strength effect on orientation
19	discrimination can explain the results from Experiment 1.

1	We hypothesized that under strong signal strength (large modulation amplitude)
2	conditions, frequency discrimination thresholds might not be as affected by the
3	modulation amplitude and would remain constant at the saturation level whereas they
4	would be increased under low signal strength (small modulation amplitude) condition.
5	To test this hypothesis, we estimated the perceptual strength of the stimuli in
6	Experiment 1, which is considered to correspond to the signal strength of the stimuli
7	such as the contrast of the grating stimuli in orientation discrimination, and examined
8	the dependence of radial frequency discrimination on perceptual strength.
9	These estimations were carried out by dividing the stimulus modulation parameter r_0A
10	of the RF pattern by the amplitude thresholds to detect the deformation of the base
11	circles which were reported in our other study (Feng et al., in review).
12	Table 1
13	Table 1 lists the amplitude detection thresholds reported and the estimations represented
14	as the multiples of the deformation threshold. The perceptual strength increases as the
15	eccentricity decreases, from 1.8 to 7.3 for $r_0A = 0.12$, from 3.5 to 14.5 for $r_0A = 0.24$
16	and from 7.1 to 29.1 for $r_0A = 0.48$. If the asymptote at which the signal strength effect
17	saturates is approximately 7 times the detection threshold, our hypothesis might suggest
18	that above this level, the radial frequency discrimination thresholds may hold constant,

whereas they may decrease with increasing signal strength up to the abovementioned
 asymptote.

3	The exception to this suggestion is the lack of a decreasing in threshold for the RF
4	patterns when the radius decreases from 8 deg to 4 deg and the signal strength increases
5	from 3.6 to 7.3 in the case of $r_0A = 0.12$ deg. However, the hypothetical suggestion is
6	true in all the other conditions. It is not unreasonable that the radius size effect of the
7	radial frequency discrimination seen in experiment 1 can be well explained by the
8	context concerning the signal strength effect on orientation discrimination.
9	As a result, our finding that the radial frequency discrimination thresholds as a function
10	of radius were dependent on the modulation amplitudes of the RF patterns is ascribed
11	to the eccentricity effect reported in our other study (Feng et al., in review). wherein
12	the deformation thresholds required to discriminate the RF pattern from a circle
13	increased with increasing stimulus eccentricity. Our results showed similar properties
14	to previous studies concerning orientation discrimination performances, suggesting that
15	the local contour orientation may be a critical cue for discriminating different frequency
16	RF patterns.
17	We mention here that the effect of number of cycles of modulation of RF patterns should

18 be examined to investigate locality or globality (global integration) of information

19 processing of RF pattern in the peripheral field.

23

1	Dickinson, McGinty, Webster and Badcock (2012) showed that the detection thresholds
2	from circle described by gradient at a zero crossing decrease with increasing the number
3	of cycles of modulation, being coincident at each value for number of cycles of
4	nodulation regardless of RF. In a future work, we will examine the effect of number of
5	number of cycles of modulation on frequency discrimination threshold between
6	different RF patterns.

1 Experiment 2

2 Magnified RF pattern

3	In experiment 1, using a constant CCF RF pattern, the radial frequency discrimination
4	thresholds as a function of radius were influenced by the eccentricity effect, wherein
5	the deformation thresholds required to discriminate the RF pattern from a circle
6	increased with increasing stimulus eccentricity. Experiment 2 was designed to test
7	whether spatial scaling (the retinocortical transformation) can neutralize the
8	eccentricity effect observed in experiment 1.
9	There exist many magnification factors reported (Anstis, 1974; Farrell and Desmarais,
10	1990; Higgins et al., 1996; Levi et al., 1985; Rovamo and Virsu, 1979; Melmoth and
11	Rovamo, 2003; Schwartz, 1977; Watson, 1987; Whitaker et al., 1992). In the present
12	experiment, we used Schwartz's retinocortical mapping function.
13	We constructed a series of magnified stimuli with different radii that had the same form
14	in the V1 field and examined the dependence of the radial frequency discrimination
15	thresholds for the magnified patterns on stimulus radius.
16	The magnified RF patterns with the CCF being inversely proportional to the radius of
17	the stimuli, were created using Schwartz's retinocortical mapping function. Schwartz
18	showed that the two-dimensional retinocortical mapping functions are represented in
19	complex variables as in equation (5) (Schwartz, 1977):

2	where the complex variable Z represents a point in the retinal plane; the complex
3	variable W represents a point on the cortical plane; a defines the extent of the foveal
4	singularity; and k is a scaling constant. For the value of a, there is rough consensus that
5	the primate visual cortex is, to a first approximation, a complex logarithmic structure
6	characterized by a foveal constant ranging from $a = 0.3$ deg to $a = 0.9$ deg (Wilson et
7	al., 1990). In this study, we used $a = 0$ for the retina cortex function because our
8	experimental condition was focused on $z \ge 4$ deg.
9	If one changes r_0 and σ in proportion to the changing eccentricity while maintaining A
10	and ω constant, then the changed patterns have a similar form; however, their radii are
11	different and are dependent on eccentricity in a linear manner. If these changed patterns,
12	as shown in Fig. 5 (a) (the magnified RF patterns), are transformed from the retinal
13	plane into the cortical plane using equation (6), the transformed patterns are different
14	in position in the cortical plane; however, they have the same forms and radii, which
15	implies that all transformed patterns activate the cortical area equally.
16	In this experiment, we used the magnified RF patterns with an identical reference RF.
17	The reference RFs (9 and 18 cycles/360 deg) were held constant within a session but
18	were different across sessions. The amplitude modulations (A) of the target and

19 reference RF patterns were held constant within a session but were different across

1

sessions (0.03 and 0.06), as shown in Fig. 5 (b).

2

Fig. 5

3 Results

4	For the magnified patterns, the thresholds were measured as a function of the pattern
5	radius over a range from 4 to 16 deg. In Fig. 6, the means of the thresholds for the five
6	participants are plotted against the radius under the four conditions ($\omega_R = 9$ cycles/360
7	deg and A = 0.03; ω_R = 9 cycles/360 deg and A = 0.06; ω_R = 18 cycles/360 deg and A =
8	0.03; and $\omega_R = 18$ cycles/360 deg and A = 0.06). As shown in Fig. 6, the thresholds
9	remained constant across all radii, approximately 1.1, and regardless of the other
10	stimulus parameters. To test for significant differences in the group data, we used a
11	three-way ANOVA. ANOVA with the factors of radius, A and ω_{R_i} was used to test for
12	main effects. Based on the results, no main effect for the three factors: radius, F (3, 12)
13	= 4.771, p = 0.086; A, F (1, 4) = 0.25, p = 0.643; and ω_R , F (1, 4) = 0.019, p = 0.896
14	has been found.

15

Fig. 6

16 The radial frequency discriminability of the target stimuli from the reference stimulus 17 is represented by the difference between the response frequencies corresponding to the 18 "higher" responses and the "lower" responses. Fig. 7 shows the cumulative 19 discriminability of the target from the reference stimuli versus the target radial

1	frequency over all participants and the four radii for each magnified pattern ($\omega_R = 9$
2	cycles/360 deg and A = 0.03; ω_R = 9 cycles/360 deg and A = 0.06; ω_R = 18 cycles/360
3	deg and A = 0.03; and ω_R = 18 cycles/360 deg and A = 0.06). A positive value on the
4	ordinates indicates the magnitude of discrimination performance for a target that the
5	participants judge to have a higher frequency than the reference frequency (9 cycles/360
6	deg), whereas a negative value indicates the magnitude of discrimination performance
7	for a target that the participants judge to have lower radial frequency than the reference
8	frequency. Discriminability increases as the target radial frequency increases (or
9	decreases) from the reference frequency of 9 cycles/360 deg. The discriminability
10	function shows a linear function of target frequency on the logarithmic scale within the
11	frequency domain being presented.
12	Fig. 7
13	Discussion
14	Comparison of our discrimination thresholds with the identification accuracies in
15	previous studies
16	Wilkinson et al. (1998) found that participants were able to identify RF patterns of 6 or
17	less cycles with an accuracy of over 90% and 7 or more cycles with an accuracy of 60%
18	or less. These identification accuracies were also observed by Poirier and Wilson (2006).
19	The present study shows that the radial frequency discrimination thresholds (frequency

1	ratio) are approximately 1.1 for RF patterns with a large stimulus size ($r_0A = 0.48$) and
2	for the magnified stimuli, as shown in Fig. 4 (3) and Fig. 6, respectively.
3	Although these results cannot be compared with the identification accuracies in studies
4	by Wilkinson et al. (1998) and Poirier and Wilson (2006) because of the different
5	stimulus conditions, the logarithms of the ratios of 5 cycles to 6 cycles ($6/5 = 1.2$) and
6	6 cycles to 7 cycles $(7/6 = 1.16)$ are larger than our radial frequency discrimination
7	thresholds. This finding suggests that 5-cycle (or 6-cycle) RF patterns are easily
8	discriminated from 6-cycle (or 7-cycle) RF patterns. The results obtained for the RF
9	patterns in this study are not inconsistent with the identification accuracies from
10	Wilkinson et al. (1998) and Poirier and Wilson. (2006).

1	<u>Frequency ratio determines the radial frequency discrimination thresholds</u>
2	Previous findings of radial frequency-selective effects, such as masking effects (Habak
3	et al., 2006; Bell et al., 2007), adaptation effects (Bell et al., 2008; Bell et al., 2009),
4	and subthreshold summation effects (Bell and Badcock, 2009), suggest that detection
5	of the RF pattern may be processed by several RF channels, each channel selectively
6	sensitive to a limited band of radial frequencies. These channels may also be involved
7	in the suprathreshold perception of radial frequency and of the waveforms of RF
8	patterns. If this is so, the ability to discriminate between different radial frequency
9	patterns as measured in the present study might be determined by the activity difference
10	of the multiple channels for the different patterns.
11	Fig. 6 indicates that the radial frequency discrimination thresholds for the magnified
12	RF stimuli were the same for two different reference frequencies (9 and 18 cycles/360
13	deg), implying that the ability to discriminate between the two different stimuli
14	depends primarily on the ratio of their radial frequencies over a wide range of absolute
15	radial frequencies. That we found equally discriminable radial frequencies to differ by
16	nearly the same ratio may suggest that the spacing and bandwidth of the processing
17	units of RF patterns may be more uniform if expressed on a logarithmic rather than a
18	linear scale.
19	It should be mentioned here that the spatial frequency bandwidths of cortical cells

- 1 <u>turned to different spatial ranges have bandwidths that are roughly constant on a ratio</u>,
- 2 or logarithmic, scale (De Valois and De Valois 1990). Thus, equal logarithmic channel
- 3 <u>bandwidths have been reported for spatial frequency selectivity.</u>
- 4 Our experimental results that the radial frequency discrimination thresholds were the
- 5 same for the two different reference frequencies (9 and 18 cycles/360 deg) may be
- 6 explain by a multiple channels model with equal logarithmic channel bandwidths of RF.

1 Conclusion

2 We found that the discrimination thresholds expressed by the frequency ratio between 3 RF patterns of different frequencies vs radius functions for the constant CCF RF patterns indicated different functional forms dependent on the modulation amplitude of 4 the RF patterns. This dependence was ascribed to the eccentricity effect wherein the 5 deformation thresholds for discriminating the RF pattern from a circle increase with 6 increasing stimulus eccentricity (Feng, et al. in review). 7 8 And we found that the discrimination thresholds vs radius functions for the magnified 9 RF patterns were flattened for different modulation amplitudes and frequencies. The thresholds were similar at all eccentricities. Cortical magnification neutralized the 10 11 eccentricity effect observed for the constant CCF patterns.

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- 14 2018



2 Fig. 1 Time course of the radial frequency discrimination experiment. Each trial consisted of two 200 ms stimulus presentation intervals with a 300 ms ISI and a 3 response interval; one presentation interval contained a reference stimulus, while the 4 5 other presentation interval contained a target stimulus. The participants were instructed to indicate whether, compared to the first stimulus (S1), the frequency (ω) of the second 6 7 stimulus (S2) was higher, lower or the same using one of three buttons: one button for the S2 frequency being higher than the S1 frequency, another button for the S2 8 9 frequency being lower than the S1 frequency, and a third button for the S2 frequency 10 being the same as the S1 frequency.



1

2 Fig. 2 Derivation of radial frequency discrimination thresholds

3 We used a three-alternative forced-choice procedure. The responses of the participants 4 were composed of the "higher", "lower" and "same" responses. Based on the proportion of correct "higher" and "lower" responses versus the target radial frequency, we 5 6 obtained a logistic curve equation, where the relative proportions of the "lower" and the "higher" responses are expressed from 0 to 100% on the ordinate. The abscissa 7 indicates the target radial frequency from 6 to 13 cycles/360 deg, and 9 cycles/360 deg 8 9 is the reference radial frequency (ω_R). From the logistic curve, we obtained two key 10 points on the abscissa, ω_{TH} , the frequency where the participants achieved 75% on the ordinate, and ω_{TL} , the frequency where the participants achieved 25% on the ordinate. 11 12 We calculated the radial frequency discrimination thresholds by using the following equation: 13

14 Discrimination threshold =
$$\frac{\ln(\omega_{TH}) - \ln(\omega_{TL})}{2} = \ln\left(\left(\frac{\omega_{TH}}{\omega_{TL}}\right)^{\frac{1}{2}}\right)$$





1 Fig. 3 Constant circular contour frequency (CCF) patterns.

2	To examine the dependence of radial frequency discrimination thresholds on the radius
3	(eccentricity), we use a series of CCF constant patterns with different radii (4, 8, 12 and
4	16 deg). The CCF is considered to be an important factor in the visual performance of
5	RF patterns regardless of radial frequency or radius (see text).
6	(a) shows schematic examples explaining how two patterns with different radii (r_0) and
7	radial frequencies (ω) have the same circular contour frequency (CCF = 0.159 cycles/cl-
8	deg). CCF is defined by the number of radial cycles per deg of unmodulated contour
9	length measured in deg of viewing angle and calculated by $\omega/2\pi r_0$
10	(b) shows three series of reference patterns with a constant CCF of 0.358 cycles/cl-deg
11	and a constant MOD $(A \boldsymbol{\omega}_R)$ used to examine the dependence of the pattern radius in
12	experiment 1. Here, MOD is the Maximum orientation difference between the RF
13	pattern and the unmodulated circle. The reference radial frequency (ω_R) increases with
14	increasing radius to keep the CCF constant (0.358 cycles/cl-deg); meanwhile, the σ of
15	the patterns remains constant ($\sigma = 1$ deg). The absolute modulations (r_0A) of the target
16	and the reference RF patterns hold constant (0.12, 0.24, 0.48 deg as shown in (1), (2)
17	and (3)) within a session but are different across sessions. And also, MODs of the
18	reference stimuli holds constant (A ω_R = 0.27, 0.54, 1.08) within a session. We use seven
19	radial frequencies for the target stimuli (ω_T): the same frequency as the reference, and

1	three higher and three lower than that of the reference. We use 14 deg instead of 16 deg
2	when $r_0A = 0.12$ deg because of the impossibility of measurement otherwise.
3	Meanwhile, we use 31 cycles/360 deg as the reference stimulus to keep the CCF
4	constant. Note here that four constant CCF reference patterns with different radii within
5	a session have the same orientation difference between RFs and a circle at crossing
6	point.





2 Fig. 4 Results of radial frequency discrimination for experiment 1.

Mean discrimination thresholds for the five participants plotted against the radius (4, 8, 12 and 16 deg). Thresholds (frequency ratio) are expressed as the square root of the higher frequency/lower frequency on the ordinate. The absolute amplitude (r_0A) was held constant in each session but was varied across sessions; discrimination thresholds are shown for the small stimulus size: 0.12 deg (1), the middle stimulus size: 0.24 deg

- 1 (2), and the large stimulus size: 0.48 deg (3). When $r_0A = 0.12$ deg, the threshold for 16
- 2 deg is estimated from the thresholds for 12 and 14 deg that were measured in the
- 3 experiment. Error bars = 1 S.E.





1 Fig. 5 Magnified patterns in experiment 2.

2 (a) shows schematic examples created by using Schwartz's retinocortical mapping 3 function. These patterns are different in position in the cortical plane but have the same forms and radii, implying that all the transformed patterns activate the cortical area 4 5 equally. 6 (b). shows the four series of reference magnified patterns used in experiment 2. σ increases with increasing radius, while the radial frequency (ω_R) and amplitude are 7 constant ($\omega_R = 9$ cycles/360 deg, A = 0.03, $\omega_R = 9$ cycles/360 deg, A = 0.06, $\omega_R = 18$ 8 9 cycles/360 deg, A = 0.03 and ω_R = 18 cycles/360 deg, A = 0.06 as shown in (1), (2), (3) 10 and (4)) within a session but are different across sessions. Note here that four magnified 11 reference patterns with different radii within a session have the same orientation 12 difference between RFs and a circle at crossing. And also, MODs of the reference 13 stimuli holds constant (A ω_R =0.27, 0.54, 0.54, 1.08) within a session but are different across sessions. 14





Radius (ro) (deg)



Mean discrimination thresholds for the five participants plotted against the radius (4, 8, 12 and 16 deg). Thresholds (frequency ratio) are expressed on the ordinate. The amplitude (A) and the radial frequency of the reference stimulus (ω_R) were held constant within a session but varied across sessions: A = 0.03; ω_R = 9 cycles/360 deg (1), A = 0.03; ω_R = 18 cycles/360 deg (2), A = 0.06; ω_R = 9 cycles/360 deg (3), and A =

8 0.03;
$$\omega_R = 9$$
 cycles/360 deg (4). Error bars = 1 S.E.




Target Radial Frequency (cycles/360 deg)

Fig. 7 Discriminability of the target from reference stimuli versus target radialfrequency.

4 The responses of the participants consist of their "higher", "lower", or "same" 5 responses. The difference between the response frequencies of the "higher" responses and the "lower" responses is considered to represent the radial frequency 6 discriminability of the target stimuli from the reference stimuli. Each panel shows the 7 cumulative difference between the response frequencies of the "higher" responses and 8 9 the "lower" responses over all participants and the four radii for each magnified pattern $(\omega_R = 9 \text{ cycles}/360 \text{ deg}, A = 0.03; \omega_R = 9 \text{ cycles}/360 \text{ deg}, A = 0.06; \omega_R = 18 \text{ cycles}/360$ 10 deg, A = 0.03; or ω_R = 18 cycles/360 deg, A = 0.06). Error bars = 1 S.E. The observed 11

1	small error bars imply little l variance across the participants and radii. Discriminability
2	increases as the target radial frequency increases (or decreases) from the reference
3	frequency of 9 cycles/360 deg. The discriminability function shows a linear function of
4	target frequency on the logarithmic scale within the frequency domain being presented.

1Table 1 The deformation thresholds in our other study and the stimulus2modulation amplitudes (A) in the present study

	Results of our other study (Feng, et.al. in review)	Stimulus frequency	parameters fo discrimination	r the radial experiment
Radius		$r_0A = 0.12$	$r_0A = 0.24$	$r_0A = 0.48$
(deg)	Amplitude	deg	deg	deg
r ₀	threshold amplitude	perceptual	amplitude (A	/threshold)
4	0.0041	7.3	14.5	29.1
8	0.0042	3.6	7.2	14.4
12	0.0041	2.5	4.9	9.8
16	0.0042	1.8	3.5	7.1



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Visual Context: An fMRI Study **Connectivity within Cortical** Pathways Are Distinguished for Different Categories of Modes of Effective **Mushroom Bodies and Central Complex in Visual Learning of Different Roles for Honey Bee Colored Lights in an Aversive Conditioning Assay**

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Modes of Effective Connectivity within Cortical Pathways Are Distinguished for Different Categories of Visual Context: An fMRI Study

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 Modes of Effective Connectivity within Cortical Pathways Are Distinguished for Different Categories of Visual Context: An fMRI Study. Front. Behav. Neurosci. 11:64. doi: 10.3389/fnbeh.2017.00064 Context contributes to accurate and efficient information processing. To reveal the dynamics of the neural mechanisms that underlie the processing of visual contexts during the recognition of color, shape, and 3D structure of objects, we carried out functional magnetic resonance imaging (fMRI) of subjects while judging the contextual validity of the three visual contexts. Our results demonstrated that the modes of effective connectivity in the cortical pathways, as well as the patterns of activation in these pathways, were dynamical depending on the nature of the visual contexts. While the fusiform gyrus, superior parietal lobe, and inferior prefrontal gyrus were activated by the three visual contexts, the temporal and parahippocampal gyrus/Amygdala (PHG/Amg) cortices were activated only by the color context. We further carried out dynamic causal modeling (DCM) analysis and revealed the nature of the effective connectivity involved in the three contextual information processing. DCM showed that there were dynamic contextions and collaborations among the brain regions belonging to the previously identified ventral and dorsal visual pathways.

Keywords: contextual information, color context, shape context, 3D-depth context, fMRI, dynamic causal modeling

INTRODUCTION

Context contributes to accurate and efficient information processing, thoughts and actions. Along with predictive coding, which is a guiding principle of efficient information processing in the brain, contextual information allows for context-driven predictions or expectations. Thus, humans can recognize thousands of objects in a cluttered scene, despite variability in pose or changes in object occlusion. However, little is known about the dynamics of the neural mechanisms that support these abilities.

Previous studies (Rugg et al., 1999; Rüttiger et al., 1999; Scholl and Pylyshyn, 1999) have shown that visual contextual processing is carried out hierarchically in several brain domains. Within the spatial domains, one type of contextual information is the feature context, which is the "glue" that binds visual features to coherent objects and scenes. Neural sites responsible for feature context processing include the inferior frontal gyrus (IFG), inferior temporal gyrus (ITG), inferior parietal lobe (IPL), and postcentral gyrus (PG) (Kwon et al., 2016).

Another type of contextual information is the association context of object and color, which plays a role in object recognition based on prior knowledge (memory color). Recent functional magnetic resonance imaging (fMRI) studies demonstrate that the parahippocampal gyrus (PHG), IFG and ITG contribute to the processing of association context (Kourtzi and Kanwisher, 2000; Haxby et al., 2001; Boccia et al., 2016; Kwon et al., 2016). The feature and association contexts allow the visual system to sensitize the corresponding visual representations for easier recognition of the adjacent objects once attended. In this sense, the attentional system is closely related to the contextual information processing system. It has been shown that the visual attentional system is a network that consists of early visual regions, such as Brodmann's areas 17/18/19, fusiform gyrus (FG), superior/inferior parietal cortex (SPL/IPL) and frontal eye fields (FEF) (Coull and Nobre, 1998; Nobre et al., 1998). Activation of these neural regions has been proposed to be relied on an intrinsic interplay between exogenous and endogenous sources of information in then distinctly distributed neural networks in the lateral prefrontal cortex (PFC) (Miller and Cohen, 2001; Rowe et al., 2005). However, to better understand the dynamics of the mechanisms involved in these neural sites and networks, anatomically precise models are needed to define how the connections change with context.

In the present study, we focused on the dynamics of the neural mechanisms underlying accurate object recognition despite variability in the visual contexts (Figure 1). We analyzed the dynamics by imaging the neural activations of subjects while responding to the objects of different color, shape and 3D-depth. The findings provide new evidence for existence of subnetworks within the recognized visual context processing networks and further our understanding of neural dynamics.

METHODS

Subjects

Twenty-one subjects were enrolled. The subjects were all right-handed, with a means \pm SD age of 22 \pm 2.6 years (14 females and 7 males). All subject had no history of neurological or psychiatric illness, and had normal or corrected-to-normal vision. All procedures were approved by the ethics committee of China Medical University (Human Studies Protocol number 2010PS11) in accordance with the declaration of Helsinki (2008). Informed written consent was obtained from each of the subjects before the scanning session.

Stimuli

We employed stimuli with valid and invalid contexts to identify the brain regions involved in the visual association processing of objects of different color, shape and 3D-depth (**Figure 2A**). In order to find the modulatory effect, we employed a pair of contrast conditions for each context: natural vs. unnatural color, interwoven vs. stacked shape and normal vs. abnormal 3D scene. For each set of objects, 50 valid or invalid stimuli were presented.

For color stimuli, photos of fruits and vegetables were used. The invalid images were prepared by changing the CMYK composition of the photos while maintaining a constant yellow color across the photos. The objects were presented at the center of a visual field on gray background at a visual field of $8^{\circ} \times 8^{\circ}$.

For shape stimuli, three geometric figures a circle (green), an equilateral triangle (yellow) and a square (light-green) were used to interweave each other. For the valid stimuli, the figures were stacked but not interwoven, while for the invalid stimuli, the figures were interwoven such that the original shapes of the figures were disrupted, giving rise to the impression that one part of an object is in front of another and/or that the objects have complex shapes embedded in each other like a jigsaw puzzle. The objects were presented as described above.

For 3D-depth conditions, images with three pictorial depth cues were used. The cues included linear perspective cue (a corridor), a size cue (two people, assumed to have identical body size) and a height-in-field cue (the positions of the two people in the corridor). In the valid stimuli, the images depicted a scene in which the three depth cues were globally consistent. In the invalid stimuli, the three depth cues did not globally match each other. The images were presented at the center of the visual field on a gray background with a visual angle of $15^{\circ} \times 15^{\circ}$.

Experimental Procedure

The experiments were conducted in two phases. In the first phase, the 21 subjected were trialed three times with the three context conditions in 5 sessions. In the first three session, only one of the three conditions was presented, while in the last two sessions, all conditions were presented. In the trials, an event-related design was used. In each run, trials for the valid and invalid stimuli were intermixed with an inter-stimulusinterval (ISI) in a predetermined order for each functional run as described previously (Vallesi et al., 2012). In each trial, stimuli were presented for 2s after a 1s fixation. The ISI between two consecutive context-valid or invalid stimuli was $0 \sim 3$ s, between alternative context-valid or invalid stimuli was 9~12 s (Figure 2B). The subjects were instructed to continuously fixate on the central point of the objects to be judged and press the right or left button as quickly as possible when the context was valid or invalid. To eliminate the judgment errors due to task difficulty, the conditions were carefully matched for difficulty (for detail, see Results). The results obtained in the first phase were used to define the region of interest (ROI) for dynamic causal modeling (DCM) analysis. Each run contained 25 valid and invalid trials in the first phase.

In the second phase, the 21 subjects were stimulated twice in the same three sessions as in the first phase in an event-related design similar to that used in the first phase. Each run consisted of



150 trials, and during each trial, one stimulus randomly selected from the one of three stimulus sets was presented. The ISIs and the order of stimuli were predetermined based on the procedure used in the fMRI runs during the first phase. The time series data generated in the second phase were used for DCM analysis.

Evaluation of the Adequacy of the Stimulus Judgment

To evaluate the adequacy of judgment for visual contexts, we employed the procedure of the semantic differential (SD) method based on the data from a total of 300 stimuli as a psychometrically controlled scale of contextual validity (Paller et al., 2007).

To rate the contextual validity, bipolar adjective scales with seven-point ratings were used (Figure 3A). Ten subjects were given the instructions that are essentially the same as those used by Osgood and Suci (1955). As shown in **Figure 3B**, it was clear that the judgment profiles were quite distinct between the valid and invalid stimuli, indicating that the characteristics of the stimuli were clearly recognized and the stimuli were appropriate.

Experimental Setup

Visual stimuli were generated on a personal computer (DELL desktop computer) and presented to the subjects via a custom-built magnet-compatible video system. The stimuli were projected onto a vertical screen positioned between an MR scanner and the projector. The subjects viewed the visual stimuli via a mirror above their eyes. The distance between the screen and the mirror was 190 cm. A color LCD projector (Epson, 1,024 \times 768 pixels, 60 Hz refresh rate) was used to present the stimuli.



fMRI Experiment

Whole-brain fMRI scans were performed and acquired using a Philips 3.0T Intera scanner with gradient echo-planar imaging sequences (TR: 3,000 ms, TE: 50 ms, flip angle (FA): 90°, matrix size: 128×128) while the subjects were judging the context validity. The acquired slices were axial and parallel to the anterior-posterior commissure line (voxel size $1.8 \times 1.8 \times 4$ mm). Thirty two slices were obtained from the bottom to top.

Standard whole brain structural scans (3D MPRAGE, sagittal acquisition, slice thickness 1.0 mm, in plane resolution 1.0 \times 1.0 mm²; TR: 8.3 ms; TE: 4.6 ms; FA: 8°; SENSE factor: 2) were also obtained for the participants.

Statistical Parametric Mapping

The fMRI data were analyzed using SPM8 (Wellcome Department of Cognitive Neurology, London, UK) implemented in MATLAB (MathWorks, USA). For each subject, the first four images were discarded and the remaining 143 images from individual runs were realigned to correct head motion and hemodynamic artifacts, using the mean image as a reference. The motion parameters generated in the spatial realignment indicated that the 21subjects moved less than 4mm on average.

The realigned images were spatially normalized to the MNI (Montreal Neurological Institute) brain template (Ashburner and Friston, 1999). The normalized images were smoothed spatially with an isotropic 8 mm FWHM (full-width at half maximum) Gaussian kernel and re-sampled, resulting in voxels of $2 \times 2 \times 2$ mm in size.

To identify the neural substrates that process the three visual contexts and to assess the significance of functional activation, we used a general linear model (GLM) analysis. In the first level (within-subject) analysis, the data were modeled voxelwisely in GLM. The data were high-pass filtered (cut-off, 128 s) to remove low-frequency signal drifts and scaled down the number of images to 143 within each session. Non-sphericity of the error covariance was accommodated by an AR (1) (first-order autoregressive) model in which the temporal autocorrelation is estimated by pooling over supra-threshold voxels (Friston et al., 2002). Contrast images were created for each subject. There were 18 contrasts for the second-level group statistics: (1-6) valid vs. invalid and invalid vs. valid context of color (C), shape (S), and 3D-depth (D), which were used to define the difference between validity within conditions; (7-9) common activations of C, S and D, or C and S, or S and D, (10-12) common activations of valid



and invalid context of C, S or D, (13) C vs. (S+D), (14) S vs. (C+D), (15) D vs. (C+S), (16) (S+D) vs. C, (17) (C+D) vs. S, (18) (C+S) vs. D. The contrast (con) images from the first-level analyses of all 21 subjects were used for the second-level analyses. To identify the areas activated both by valid and invalid stimuli in the C, S, and D conditions, or under all conditions, one-sample *t*-test analysis was carried out for each of the 9 con images. The resulting SPM (T) maps were then thresholded at p < 0.05 (cluster-level corrected, FWE; cluster forming threshold: p

< 0.001, uncorrected). Among the 18 contrasts mentioned above, only statistics 7–13, 16–18 showed significant activations at the corrected threshold level. These results were then used to define the region of interest (ROI) for DCM analysis.

Dynamic Causal Modeling

ROIs were defined by manually tracking the intersection of anatomical boundaries and significant functional activation informed by the results of the SPM analysis of the data. Dynamic causal models (Stephan et al., 2007) were fitted to subject-specific BOLD time series that were extracted from the data from the mixed sessions of fMRI runs. Because the exact locations of the activated areas vary across subjects, it is important to ensure that the models are comparable across subjects. To ensure this, we defined ROIs such that the extracted time series met a combination of anatomical and functional criteria. Anatomical boundaries were defined on the MNI template using automated anatomic labeling (AAL) toolbox (http://www.fmri.wfubmc.edu/cms/software#PickAtlas). ROIs for the respective areas were selected according to the results of the group analysis. We defined location of the individual (single-subject) ROIs by the local peals closest to the group coordinates in the respective cortical regions (Stephan et al., 2007).

For each subject and area, individual local peaks (p < 0.05 uncorrected) for the respective contrast were identified as described above for the mixed tasks (Eickhoff et al., 2009). Time

series for these regions were then extracted as the first principal component for 15 most significant voxels in the target contrast centered around the individual peaks in a radius of 4 mm and adjusted for the effects of interest in SPM8.

Construction of DCMs

To preform DCM, we assumed that the stimulus presentation directly evoked brain activity in early visual areas [middle occipital gyrus (MOG)18/19] regardless of the type of context. By using empirical evidence regarding the dorsal attentional network (Coull and Nobre, 1998; Nobre et al., 1998), the network for the associative context (Rowe et al., 2005), the neural pathway for the visual processing of depth (Kourtzi et al., 2003), and the neural substrates that process the three visual contexts identified through SPM analysis, we determined the regions, connections, and driving inputs to be used to construct the basic models of processing streams for the color, shape and 3D-depth contexts. **Figure 4A** shows models of the intrinsic connectivity defined for



FIGURE 4 | Supposed intrinsic connectivity, modulatory influence and driving input in DCM models. (A) Intrinsic coupling of proposed basic dynamic network models for the neural information processing during the judgments for C, S, and D conditions. (B) Modulatory influence of color, shape and 3D-depth on coupling during three conditions; (C) Photic inputs to the dynamic network.

each condition; **Figures 4B**, **10** show the putative positions of modulatory influence to intrinsic connectivity for each model tested, and **Figure 4C** shows MOG, the entering point for photic input to the brain. For each condition, 9 models were tested for left and right hemispheres.

Bayesian Model Comparison

To determine the optimal model structure based on the data observed from all subjects for each condition, the RFX Bayesian model selection (BMS) was used. The posterior probability model was obtained by taking the product of the model evidence from each subject-specific DCM and its prior model (Penny et al., 2004). The model evidence, as approximated by the free energy, depends not only on model fit but also on model complexity. Because the fixed effects group analysis can be distorted by outlier subjects, BMS was also implemented using a hierarchical Bayesian model to estimate the parameters of a Dirichlet distribution over the probabilities of all models considered (implemented in SPM8). These probabilities define a multinomial distribution over model space, enabling the computation of the posterior probability of each model given the data of all subjects and the models considered. For BMS, random effect tests were applied for each model using exceedance



probability, which is used as posterior probability. Bayesian model averaging (BMA) was also carried out for each condition and hemisphere, because of no optimal model survived a posterior exceedance probability (EP) of 0.7. For example, an EP of 0.7 means that we can be 70% confident that a specific model has a greater posterior probability than any other models. In the case of only two competing hypotheses, the EP is particularly intuitive as it describes the confidence that a model is more likely than the other one. For the averaged model, the subject-specific intrinsic, modulatory and extrinsic effects were also tested using one-sample *t*-tests. In addition, photic inputs, modulatory influence and connection strengths were analyzed as described (Daunizeau et al., 2011).

RESULTS

Behavioral Results

To dissociate the neural networks responsible for visual processing of the three contexts (color, shape, and 3D-depth), we designed the conditions that were equalized for the difficulty of judging the contextual validity. To evaluate the validity of our task design, mean reaction times (RTs) and accuracy were used as measures of behavioral performance. As shown in **Figure 5A**, mean RTs in 5 fMRI sessions for valid- and invalid- stimuli were different among the three conditions (p < 0.001). However, no difference was observed between valid- and invalid- stimuli (p = 0.054). The subjects required significantly longer time to make a



FIGURE 6 | Activation maps while judging the contextual validity for the three visual contexts.

x

-50

-14

-20

-34

-26

-36

-42

-44

42

48

42

32

32

36

-34

-34

-48

-52

12

48

46

12

-14

-28

-32

28

-52

у

-56

-92

-90

-42

-64

-48

-36

8

-32

8

4

20

-12

14

20

26

38

10

16

-22

-16

-14

-10

-94

-94

-90

-64

z

-18

-10

-10

-34

46

-16

40

36

46

28

58

-6

50

6

0

 $^{-4}$

12

18

44

34

58

8

8

10

8

2

-12

t-score

9.47

8.3

8.18

7.75

6.87

6.83

6.25

9.97

9.15

8.69

8.65

8.35

8.31

8.21

8.03

7.86

7.81

7.73

7.7

7.69

8.05

5.84

11.48

11.26

10.98

10.14

8

TABLE 1 Activated regions during judgments of contextual validity fo	r
visual contexts.	

TABLE 1 | Continued

Cluster size (voxels)	Anatomical regions and BA	t-score	x	У	z	Cluster size (voxels)	Anatomical regions and BA
							L fusiform gyrus BA 37
5238	L inferior frontal gyrus	11.33	-44	34	8		L inferior occipital gyrus BA 17
	BA 40	10.14	30	24	10		L fusiform gyrus BA 18
	BA 47	10.14	-32	24	-10		L cerebellar tonsil
	L middle frontal gyrus BA 9	9.19	-46	14	32		L superior parietal lobule BA 7
	L inferior frontal gyrus BA 44	8.12	-48	10	16		L fusiform gyrus BA 37 L inferior parietal lobule
	L putamen	7.02	-18	10	6		BA 40
	L middle frontal gyrus BA 10	6.75	-36	40	20		L middle frontal gyrus BA 9
	L middle frontal gyrus BA 6	5.69	-54	4	42		R inferior parietal lobule BA 40
302080	R inferior frontal gyrus BA 47	10.49	32	22	-8		R inferior frontal gyrus BA 9
	L culmen	10.21	-28	-38	-26		R middle frontal gyrus
	R fusiform gyrus BA 19	10.09	46	-72	-14		BA 6 Disferier frentel europ
	R thalamus	10.02	12	-14	0		BA 47
	L middle occipital gyrus BA 18	9.81	-42	-88	2		R precentral gyrus BA 4
	L lingual gyrus BA 17	9.57	-12	-94	-12		R Insula BA 13
	R middle occipital gyrus BA 18	9.47	30	-90	-2		L insula BA 13 L inferior frontal gyrus
	L superior frontal gyrus BA 6	9.46	-6	12	56		BA 47 L inferior frontal gyrus
	L fusiform gyrus BA 19	9.11	-48	-66	-12		BA 46
	R medial frontal gyrus BA 6	9.04	10	4	60		E interior frontal gyrus BA 44
	R middle occipital gyrus BA 19	8.81	34	-90	14		R cingulate gyrus BA 32
	L parahippocampal gyrus amygdala	7.09	-18	-2	-18		R postcentral gyrus BA 2
	L precentral gyrus BA 6	6.88	-36	-6	64		R postcentral gyrus
	L middle frontal gyrus	6.75	-42	6	56	390	B thalamus
	BA 6		_			000	L thalamus
	L nodule	6.71	-2	-58	-30	3D-DEPTH	
	L inferior semi-lunar	6.07	-10 -28	-14 -62	-44	292240	L middle occipital gyrus BA 18
	L anterior cingulate BA	6.04	-8	30	24		L middle occipital gyrus BA 19
	L lingual avrus	5.85	-20	-66	0		R middle occipital
SHAPE CO	ONDITION						gyrus BA 18
316870	R middle occipital avrus BA 37	9.56	58	-64	-8		L fusiform gyrus BA 37 R medial frontal gyrus
	R fusiform gyrus BA 19	9.11	46	-70	-12		BA 6
	R inferior occipital gyrus BA 18	8	42	-86	0		R fusiform gyrus BA 37 L fusiform gyrus BA 37
	R precuneus BA 7	6.84	16	-74	44		R middle frontal gyrus
	L middle occipital gyrus BA 19	9.98	-26	-86	18		BA 6 L lingual gyrus BA 17

9.73	10	4	60
9.49	52	-70	-12
9.1	-42	-64	-12
9.07	34	2	48
9.05	-16	-94	-14

(Continued)

(Continued)

TABLE 1 | Continued

Cluster size (voxels)	Anatomical regions and BA	t-score	x	У	z
	L superior frontal gyrus BA 6	9.05	-2	14	50
	L inferior parietal lobule BA 40	8.94	-38	-44	42
	L medial frontal gyrus BA 8	8.84	-4	18	46
	L precentral gyrus BA 9	8.82	-36	8	36
	L middle frontal gyrus BA 6	8.55	-42	4	48
	L inferior frontal gyrus BA 44	7.86	-48	10	22
	L inferior frontal gyrus BA 46	7.12	-50	38	10
	L precuneus BA 7	6.7	-8	-74	48
	L culmen	6.64	-8	-32	-8
	R brainstem	6.26	8	-26	-6

decision regarding contextual validity in the S (RT: 1,325 ± 67 ms, t = 10.406; p < 0.008) and D (RT: 1,340 ± 66 ms, t = 12.72; p < 0.009) conditions than in the C condition (1,162 ± 5 ms). The RT results indicated that it was not likely that the effect of the type of visual context resulted from stimulus complexity because D stimuli were more complex than S stimuli, but the RTs did not increase in proportion to the complexity. These results suggest that visual processing for S and D conditions is different from that for C condition. As for judgment accuracy, no difference was found among these conditions (**Figure 5B**). Analysis showed that neither the main effect of stimulus condition nor the interaction between contextual validity [$F_{(1, 205)} = 1.15$, p = 0.331] and stimulus condition was significant [$F_{(1, 205)} = 0.097$, p = 0.756], indicating that any differential effect in brain activity is unlikely to be due to task difficulty.

Imaging Results Within-Task Activation

The regions that were activated during the judgment of contextual validity for each of the three visual contexts are shown in **Figure 6** and **Table 1** based on images obtained for valid and invalid stimuli. To examine the effect of the validity of visual context, we analyzed the data using the subtraction method based on a random-effects model. In six T-contrast (valid- vs. invalid- C, S, D, invalid- vs. valid-C, S, D) tests, we found no significant differences between the valid- and invalid stimuli at a threshold of p < 0.001 (uncorrected) at voxel level. Namely, for the visual contexts tested, the valid- and invalid-contexts activated the same neural regions.

Common Activation Pattern

To determine regions that were commonly activated during the judgments of validity across the different visual contexts, we used



FIGURE 7 | Common regions of activation while judging more than one conditions. (A) Common activation areas for C, S, and D conditions. (B) Common activation areas for C and S conditions. (C) Common activation areas for S and D conditions. C, color condition; S, shape condition, D, 3D-depth condition.

conjunction analysis in SPM8 to identify common activation regions (CARs) as follows:

CAR for C, S, and D Conditions

CARs during the judgments of the three contexts are shown in **Figure 7**. The color context and feature (shape and 3D-depth) contexts elicited the activations in four common regions. Based on the MNI template, the areas and coordinates of the activated areas were right MOG (x = 30, y = -88, z = 4), right SPL (x = 28, y = -62, z = 44), right FEF (x = 42, y = 0, z = 54), left MOG (x = -36, y = -88, z = 4), left SPL (x = -28, y = -64, z = 42), left FEF (x = -44, y = 8, z = 30), right FG (x = 50, y = -70, z = -12), left FG (x = -52, y = -70, z = -18).

CAR for C and S Conditions

CARs identified for C and S conditions are shown in **Figure 7B** which include the inferior temporal gyrus (ITG) and FG. The MNI coordinates of the clusters were x = 56, y = -64, z = -4 for right ITG (BA37), and x = -54, y = -60, z = -10 for left ITG (BA37).

CAR for S and D Conditions

As shown in **Figure 7C**, CARs identified for S and D conditions were IFGs located in the right hemisphere [IFG (BA45), x = 56,

y = 12, z = 24] and left hemisphere [IFG (BA45): x = -60, y = 16, z = 22].

Specific Activation Regions (SAR) for Color

SARs for color were shown in **Figure 8**. These regions were not activated by the other two object features. SARs identified included the parahippocampal gyrus/Amygdala(PHG/Amg) and frontal polar portion of the superior temporal gyrus (STG/BA38) symmetrically located in both hemispheres. The MNI coordinates of these regions were right PHG (x = 18, y = 0, z = -22), right STG (BA38) (x = 38, y = 16, z = -20), left Amg

(x = -18, y = -2, z = -18), left STG (BA38) (x = -44, y = 14, z = -20). The 4 ROIs were further defined as spheres with a radius of 8 mm to extract the signal changes for each condition.

SAR for Shape and 3D-Depth

SARs for shape and 3D-depth are shown in **Figure 9**, and they were right IPL (BA40) (x = 42, y = -32, z = 46), left IPL (BA40) (x = -42, y = -38, z = 42), right IFG (x = 38, y = 0, z = 48) and left IFG (x = -40, y = 4, z = 48). The 4 ROIs were further defined as spheres with a radius of 8 mm to extract the signal changes for each condition.



and ITG (BA38) were significantly activated (cluster-level corrected, FWE; cluster forming threshold: p < 0.001, uncorrected).



DCM Results

To reveal the dynamics in network for each condition, we carried out the DCM analysis and the results are shown in **Figure 10A** (BMS-RFX) and **Figure 10B** (BMA) for each hemisphere. BMS-RFX results showed that, for each condition and brain hemisphere, although exceedance probability for each model was different, it did not exceed 0.7, indicating that the optimal model could not be selected based on individual candidate model. Hence, the averaged effect of 9 models for each condition and brain hemisphere was calculated using BMA analysis. The BMA results showed that, for color and shape conditions, the contribution of candidate models to the DCM models was different. Models 7 and 9 had greater contribution for both shape and hemisphere. However, for 3D-depth condition, all models showed similar effect in the DCM models.

Eight models of activated sites were constructed for the processing of color (**Figures 11C,D**), shape (**Figures 11E,F**) and 3D-depth (**Figures 11G,H**). As shown, the visual stimulus inputs for color entered the system by directly activating MOG18/19. The induced activation then spread along the reciprocal connections between MOG and FG and between MOG and SPL. The activity was further expended along the reciprocal connections between FG and SPL, SPL and FEF, and SPL and FEF were based on previous studies of the dorsal attentional

network (Coull and Nobre, 1998; Nobre et al., 1998). The induced activation in FG was found spread to ITG following the method used for revealing the function of PHG (Epstein and Ward, 2010).

To define the connections for shape processing, similar procedure was adopted with slight modifications in the basic connectivity layout. Here, we focused on connections among FG, IPL, IFG, and ITG because these areas had previously been implicated to contribute to visuospatial (object and depth) tasks (Chun and Jiang, 1998; Martínez et al., 1999; Claeys et al., 2004; Hayes et al., 2004; Olzak and Laurinen, 2005; Bar et al., 2006). As in case of color, the visual stimulus inputs entered the system by directly affecting MOG18/19. The induced activation then spread along the reciprocal connections between MOG and FG, and between MOG and SPL, and expanded to SPL, FG, IPL, IFG, FEF, and ITG along their reciprocal connections (**Figures 11E,F**).

Similarly, the connections were identified for 3D-depth (**Figures 11G,H**), where the visual stimulus inputs entered the system by directly activating MOG (BA18/19) and were then transmitted along the reciprocal connections between MOG and FG as well as along the reciprocal connections between MOG and SPL, and spread to SPL, FG, IPL, IFG, and MFG.

DISCUSSION

Our findings have demonstrated that the mode of functional connectivity in the cortical pathways as well as the pattern of



activation in these pathways are distinct during the processing of different visual contexts for the first time. We have identified CARs for color, shape and 3D-depth, such as FG, SPL, and IFG, and visual context-specific activation clusters in the temporal and prefrontal cortices. Our analysis shows that processing of the association context can be distinguished by the pronounced activation of ITG (BA37), STG (BA38), and PHG (Figures 6A, 8); in the processing of shape and 3D-depth contexts, IPL, ITG (BA37) and the IFG (BA45) in the middle prefrontal gyrus are activated. These results extend previous neuroimaging evidence that the post-rolandic parietal and temporal visual cortices are important for encoding shape and 3D-depth context, whereas the temporal and parahippocampal cortices are critical for establishing the association context (Epstein and Ward, 2010). These results are also consistent with the view that contextually modulated-attentional control signals affect the neural activation in visual cortical areas (Womelsdorf et al., 2006; Roberts et al., 2007).

These new findings reveal the dynamic properties of a global functional network architecture that is characterized by two coexisting organization principles (i.e., functional segregation and integration). This architecture may play a role in the active maintenance of visual information against degradation from the mutual information that is represented within the cortices that modulate different types of information processing, where the posterior cortex is related to feature processing, the inferior cortex controls the processing of objects, the parietal cortex is involved in the processing of 3D structure, and the parahippocampal cortex affects association processing (**Figure 11**). As such, the inferior PFC may play a key role in controlling differential activations between the visual pathways that are involved in the visual processing of different types of context.

Function of PFC in the Contextual Processing of Visual Stimuli

Traditionally, PFC function in humans has been studied using a processing approach (Duncan, 2001), which assumes that cognition by the PFC can be described in terms of performance without specifying the representation that underlies these processes. In brain imaging and electrophysiology, comparisons between conditions have been made at various levels and have shown focal peaks of activity at low demand, which then evolve into a pattern of largely overlapping activity at higher demand (Scalaidhe et al., 1999; Haxby et al., 2000, 2001; Duncan, 2001; Wallis et al., 2001). On the other hand, based on a cascade model of cognitive control, Koechlin et al. (2003) showed that the engagement of prefrontal regions along the poster anterior axis is not primarily based on condition demands, such as relational complexity or memory load, instead, it is based on the



temporal structure of the representations underlying executive control. This favors the representational approach, which seeks to establish the motion that information is stored in the PFC (Goldman-Rakic, 1995a,b). Contextual processing critically relies on the active maintenance of abstract (rule-like) representations in the PFC that guides the processing in the posterior cortex (Rougier et al., 2005). Thus, our results demonstrate that distinct regions in the PFC represent visual information in different manners depending on whether or not the regions are carrying out active maintenance or rapidly updating representations of information (**Figures 11A,B**).

Effective Connectivity between the Visual and PFC

A functional brain imaging study revealed that there are largescale spatial organizations for specialization within the visual pathways (Haxby et al., 2000), and network analyses based on the anatomical links between brain regions have demonstrated the functional connectivity along the cortical visual pathways (McIntosh et al., 1994). In contrast to such large-scale analyses at successive hierarchical levels in the visual pathways, analysis of the latency of visual responses in cortical areas has yielded a somewhat different picture than what is expected on purely anatomical grounds. Such analyses have consistently found that the neurons in MT and FEF areas are activated almost as rapidly as the neurons in area V1 (Schmolesky et al., 1998; Lamme et al., 2000; Capalbo et al., 2008). Our study showed that the activated regions are converged at FEF and are specific for different types of visual information within the PFC. These results favor the evidence based on visual response latency that visual information converges at the posterior part of the PFC. Our results (Figures 11A,B) indicated that there is at least one neural site for the convergence of different types of visual information in the posterior part of the PFC.

Activation of PHG/Amygdala

DCM analysis showed that in the optimal DCM for the association context, color context had a modulatory effect on the path from FG to PHG/Amygdala. Since PHG is important for association context (Kyle et al., 2015; Boccia et al., 2016), Bar and colleagues proposed that the PHG (including the parahippocampal place area (PPA)) encodes visual context information, which they defined as information about which objects "typically co-occur in the environment around us" (Bar et al., 2008). Along this line, parahippocampal responses to visual scenes are proposed to reflect the activation of a "context frame" representation that includes information about which objects typically appear in that context and where they are likely to be located relative to each other. These authors further proposed that there is a division of labor within the PHG such that the anterior PHG primarily encodes information about the identities of the typical objects, whereas the posterior PHG (i.e., the PPA) primarily encodes information about their typical locations. In our study, we observed the activation of the bilateral anterior PHG/AMG during color conditions, suggesting that they play a role in encoding information about the identities of the typical objects, that is, a typical association between an object and its color in the natural environment.

According to the results of DCM analysis, we found that the connection strength between the FG and PHG was significant only in intrinsic connections. This may be due to 2 possible methodological issues in our experiments that might have affected PHG activation. The first was low rate of stimulus presentation at 0.33–0.5 Hz, which might lead PHG to reflect mental imagery of scenes rather than a rapid activation of contextual representations as postulated (Bar, 2004). The second was that the valid- and invalid-context stimuli might differ with respect to their low-level visual properties, which are known to affect PHG activity (Levy et al., 2001; Rajimehr et al., 2011).

Limitations

In this study, we used three visual contexts to reveal the dynamics in effective neuronal connection in the brain networks and have found specific networks for each condition. However, because we modeled the basic visual function and higher level functions such as attention and memory in the DCM models, only intrahemispheral models were presented and discussed (since the DCM analysis allows to use only 8 ROIs in one model). Further studies are need to elucidate how inter-hemisperal interactions occur in the processing of visual contexts.

CONCLUSION

Our results show that brain activations related to color context processing occur specifically in temporal cortex, including PHG/Amg, while CRAs for the three types of context processing are MOG, FG, ITG (BA37) and the dorsal attention pathway. We propose that these contexts are processed in regions in the visual cortex and dorsal attention pathways. Based on the regional activations, 9 models for each type of context processing are developed for DCM analysis. The BMA results show that color context is processed from MOG to not only the dorsal but also the ventral visual pathway, while for shape and 3Ddepth context processing, brain regions other than PHG are involved.

AUTHOR CONTRIBUTIONS

QW, ST, HS, CL, and JW designed experiments. QW, ST, HS, QG, and JW conducted experiments. QW, YE, CL, and JW analyzed data. QW, CL, JW, and TY wrote manuscript. All authors approved the manuscript.

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OPEN Cortical mechanisms for afterimage formation: evidence from interocular grouping

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Whether the retinal process alone or retinal and cortical processes jointly determine afterimage (AI) formation has long been debated. Based on the retinal rebound responses, recent work proposes that afterimage signals are exclusively generated in the retina, although later modified by cortical mechanisms. We tested this notion with the method of "indirect proof". Each eye was presented with a 2-by-2 checkerboard of horizontal and vertical grating patches. Each corresponding patch of the two checkerboards was perpendicular to each other, which produces binocular rivalry, and can generate percepts ranging from complete interocular grouping to either monocular pattern. The monocular percepts became more frequent with higher contrast. Due to adaptation, the visual system is less sensitive during the AIs than during the inductions with AI-similar contrast. If the retina is the only origin of Als, comparable contrast appearance would require stronger retinal signals in the Als than in the inductions, thus leading to more frequent monocular percepts in the AIs than in the inductions. Surprisingly, subjects saw the fully coherent stripes significantly more often in Als. Our results thus contradict the retinal generation notion, and suggest that in addition to the retina, cortex is directly involved in the generation of AI signals.

After fixating on an image for a period of time, an illusory percept in complementary luminance and colors can be observed when the original inducing image is removed. This is called negative after image (AI). AI formation has traditionally been attributed to the bleaching of retinal photoreceptors^{1,2}.

More recent work proposes that AI formation can also be affected by some perceptual and cognitive factors. For example, it has been found that AI of a pattern becomes weaker when the pattern is attended³⁻⁵. Moreover, the perceived size of the inducing stimulus determines the size of the AI⁶. Furthermore, adaptation to perceptual filing-in of a surface leads to AI of such a surface⁷. AI is also affected by contours. For instance, color appearances in AI can spread to regions not previously adapted to color, and are triggered and constrained by contours presented after the inducing stimulus⁸. Furthermore, sharp luminance edges enhance AIs more than they enhance physical stimuli of similar appearance⁹. Binding appears generally relevant in AI formation, but more strikingly, misbinding of visual features may happen in AI. For instance, color and form may be misbound in AI when misbinding is perceived during the induction phase¹⁰. Furthermore, several studies suggest that perceptual awareness affects AI. For instance, when the inducing stimuli are suppressed from awareness, the stimuli produce weaker AIs^{5,11,12}. Additionally, previously suppressed percepts initially dominate perception in AI rivalry^{11,13}.

All the work listed above, covering the topics of attention, size perception, perceptual fill-in, contextual modulation, feature binding and awareness, consistently supports the hypothesis that AI formation is not exclusively generated by retinal mechanisms, but that cortical processes are also involved in determining the AIs. We call this hypothesis the cortical generation notion. Importantly, the cortical generation notion also admits the contribution of the retina in AI formation.

Recent work by Zaidi and colleagues, however, casts doubt on the cortical generation notion¹⁴. Zaidi and colleagues found that after the removal of the inducing stimuli, the ganglion cells generated rebound responses that could provide AI signals for later neurons. Accordingly, in their abstract, they conclude that "afterimage signals are generated in the retina, but may be modified like other retinal signals by cortical processes, so that evidence presented for cortical generation of color afterimages is explainable by spatio-temporal factors that apply to all signals".

¹CAS Key Laboratory of Behavioral Science, Institute of Psychology, Beijing 100101, P.R. China. ²University of Chinese Academy of Sciences, Beijing 100101, P.R. China. ³Department of Psychology, Umeå University, S-901 87 Umeå, Sweden. Correspondence and requests for materials should be addressed to M.B. (email: baom@psych.ac.cn) In their discussion, Zaidi and colleagues¹⁴ explain this view in more detail; "Because to thalamic and cortical cells, spikes transmitted as part of retinal rebound signals are no different from any other spikes from the retina, cortical processes, such as simultaneous contrast and selective attention, should be expected to modify afterimage signals. Thus, the visually striking demonstrations of these modifications may require no new mechanisms for their explanation. Similarly, retinal rebound signals should generate filling-in under the same spatial and temporal conditions as other retinal signals ... Consequently, although cortical adaptation is responsible for many after-effects, e.g., motion and tilt, our results make it unlikely that it generates color afterimages to prolonged viewing of moderate lights." In other words, Zaidi *et al.* advocate that AI signals are exclusively generated in the retina. We henceforth call their position the retinal generation notion and point out that it stands in direct contrast to the cortical generation notion.

Evidently, Zaidi *et al.*'s¹⁴ work makes a strong case for the retinal generation notion by demonstrating that AI signals can be generated in the retina through the adaptation of retinal ganglion cells. However, adaptation affects responses at several stages of the visual hierarchy (for a review see ref. 15). This raises the question as to whether cortical adaptation may also contribute to AI formation? It seems difficult to reach an affirmative answer to the question from the previously reviewed studies which advocate cortical generation of AIs^{5,7,8,10}, since most of those studies only investigated how perceptual or cognitive factors *modulate* AIs. Modulation effects alone can be parsimoniously explained by the retinal generation notion (see the cited work by Zaidi and colleagues presented above). Nevertheless, the success of the retinal generation notion in accounting for the effects demonstrated in those studies does not imply that the cortical generation notion is necessarily wrong and should be abandoned.

The present study sought to test the validity of the cortical generation notion more directly by introducing a novel effect of interocular grouping in AIs that contradicts the prediction of the retinal generation notion. In logic, this method is called *reduction to absurdity* and is also known as "indirect proof". The routine steps in "indirect proof" is to first assume that the opposite of what you are trying to prove is true, and then seek a particular case for which predictions derived from this assumption contradict with the actual observations. The special case for the present work to test the retinal generation notion is a phenomenon serendipitously noticed in one of our studies. We observed that the percepts of complete interocular grouping were more prevalent for the AIs than for the inductions. This phenomenon is described in detail in Experiment 1. Our Experiment 2 ruled out some alternative explanations for the findings in Experiment 1. Importantly, the results in Experiments 2a and 2b showed that interocular grouping during the inductions was reduced as the inducing contrast increased.

With these two pivotal observations in mind, we may move on to the deduction process of "indirect proof". In case some readers are not familiar with indirect proof, a math example is described in the Supplementary Information. The deduction process for the present study bears much resemblance to that example. As we note, the present study tries to prove the cortical generation notion. Thus, we would first assume that the retinal generation notion is true. Generally, AIs appear after adaptation to a stimulus, and adaptation reduces the gain of the visual system. That is, the visual system is not in the same state during AIs as it is during the presentation of a stimulus with AI-similar contrast. Assuming that the retinal generation notion is correct, i.e. the retina is the only origin of AI signals, comparable contrast appearance would require stronger retinal signals in the AIs than in the inductions with AI-similar contrast. According to the findings in Experiment 2 that increased inducing contrast caused decreased interocular grouping during the inductions, we may reach a prediction that more frequent monocular patterns should be perceived in the AIs than in the inductions with AI-similar contrast. However, this prediction contradicts the empirical observations of subjects actually seeing the fully coherent stripes significantly more often in AIs. As a result, the retinal generation notion is rejected. The present study thus suggests that AI formation should also involve cortical processes in addition to the retinal mechanisms.

Results

The stimuli we used are shown in Fig. 1. Each eye was independently presented with a 2 by 2 checkerboard of horizontal and vertical grating patches. Each patch of the two checkerboards was rotated 90 degrees with respect to each other (see the top panel in Fig. 1), which produces binocular rivalry, and can generate percepts ranging from complete interocular grouping (perceiving only coherent horizontal or vertical stripes; see type IV in the bottom panel of Fig. 1) to either monocular pattern (perceiving only a checkerboard; see type I in the bottom panel of Fig. 1). Rarely, some subjects perceived the fusion between the left and the right eye image (i.e. plaid). This type V percept was measured in Experiment 2b, though not in our first experiment because it was not noticed at that time.

Enhanced interocular grouping in negative afterimages (Experiment 1). In each trial, the full contrast checkerboards were dichoptically displayed for 55 s (*i.e.* induction phase), followed by an AI phase during which all gratings were removed (see the top panel in Fig. 1). During both phases, subjects were told to report which of the four types of patterns they saw by pressing and holding one of the four keys (see the bottom panel in Fig. 1). Ten naïve subjects participated in this experiment. After a brief practice period, each subject completed 15 trials.

AIs lasted for 28.9 ± 14.6 s ($M \pm SD$). To calculate the respective predominance during the induction and AI periods, phase durations for each type of percept were summed up across all the trials during the same period. Although all four percept types were perceived approximately equally often during the induction phases (see Fig. 2a, type I: 23.0%, type II: 27.3%, type III: 27.2%, type IV: 22.5%), subjects reported seeing the coherent patterns much more frequently during the AI period than the induction period (57.9% vs. 22.5%; t(9) = 3.66, p = 0.005, Cohen's effect size index d = 1.16, 95% CI [0.14, 0.57]).

Al-mimicking induction: multiple inducing contrasts (Experiment 2a). In our original finding, the contrast of the inducers appeared much higher than those of the AIs. Therefore, the observation of interocular



or off?

Figure 1. Example stimulus presented to each eye (the top panel), and all possible stable percepts that subjects might experience (the bottom panel). The two checkerboards were rotated 90 degrees with respect to each other, which produced binocular rivalry, and could generate percepts ranging from either monocular pattern (type I) to complete interocular grouping (type IV).

grouping of dichoptic AIs being much stronger than for dichoptic inducers can simply be ascribed to the general behavior of the visual system when receiving faint input signals. To address this issue, we examined interocular grouping during low contrast inductions that mimicked the signal strength of the AIs. The key comparison is between the full-contrast-induced (FCI) AIs and AI-mimicking (AIM) inducers.

In a separate preliminary test, one author and one naïve subject empirically measured the apparent contrast of FCI AIs. Two contrast ramps were displayed during the AI phase, with their inner edges 3.5° away from the fixation point. Two ramps were placed vertically to the left and right sides of the adaptation region. Each ramp consisted of seven gratings ($1^{\circ} \times 1^{\circ}$, 1 cyc/deg in spatial frequency) in a row whose contrasts increased logarithmically from 0.01 to 0.64. Since the apparent contrast of AI was relatively high in the beginning and decreased gradually over time, the subjects kept reporting which reference grating resembled the AI most until the AI was no longer visible. Each subject completed 5 trials. The contrast for the point of subjective equality ranged between 0.04 and 0.64 (for details, see Supplementary Table S1 in the Supplemental Materials). Because we hypothesized that lower inducing contrasts would produce more coherent percepts, we selected five contrast levels biased toward the lower end of AI matched contrasts, as well as the full contrast inducer for comparison with Experiment 1 [.04.082.17.35 1]. Given that the grating with 0.04 contrast was too weak to always be perceived, subjects were also instructed to release all the keys when they failed to see anything during the induction.



Figure 2. Results of Experiments 1, 2a and 2b. (a) Predominance for the four types of percepts during the induction and afterimage (AI) phases in Experiment 1. Predominance represents the proportion of time for one of the four types of patterns perceived. (b) Time course of the integration index in Experiment 1. (c) Predominance results in Experiment 2a (Multiple inducing contrasts). The green bars indicate the predominance for the coherent percepts (type IV) during the induction of different contrast levels. The red bar indicates the predominance of type IV during the full-contrast-induced (FCI) AI phases. (d) Time course of integration index for the FCI AIs and the 0.04 contrast afterimage-mimicking inducers (AIM ind) in Experiment 2a. (e) Predominance results in Experiment 2b, and the lowest contrast AIM inducers. Error bars and the shaded areas represent standard errors of the means.

			Pe	erceptual type ($M \pm S$	D)	
	Contrast	I	II	III	IV	v
	0.04 (AIM)	$19.9\% \pm 14.4\%$	$15.3\% \pm 9.0\%$	$26.2\% \pm 9.0\%$	$38.6\% \pm 14.1\%$	
	0.082 (AIM)	$17.5\% \pm 10.5\%$	$17.5\% \pm 7.8\%$	$30.4\% \pm 8.8\%$	$34.6\% \pm 11.8\%$	
Evp 20	0.17 (AIM)	$18.9\% \pm 10.3\%$	$19.2\% \pm 7.0\%$	$33.7\% \pm 9.3\%$	$28.2\% \pm 9.2\%$	
Exp. 2a	0.35 (AIM)	$22.1\% \pm 13.6\%$	$19.3\% \pm 8.0\%$	$32.9\% \pm 10.2\%$	$25.7\% \pm 8.4\%$	
	Full (AIM)	$17.4\% \pm 10.7\%$	$20.1\% \pm 8.3\%$	$34.3\% \pm 10.2\%$	$28.2\% \pm 10.7\%$	
	Full (AI)	$4.7\%\pm5.5\%$	$10.0\% \pm 9.3\%$	$14.7\% \pm 11.0\%$	$70.6\% \pm 22.3\%$	
	Low (AIM)	$7.6\%\pm6.8\%$	$15.6\% \pm 7.8\%$	$21.9\% \pm 10.5\%$	$41.0\% \pm 13.1\%$	$0.05\% \pm 0.20\%$
	Med.(AIM)	$11.1\% \pm 7.1\%$	$21.1\% \pm 8.0\%$	$28.4\% \pm 7.6\%$	$35.8\% \pm 11.2\%$	$0.09\% \pm 0.23\%$
Exp. 2b	High (AIM)	$11.1\% \pm 8.0\%$	$23.0\% \pm 6.1\%$	$30.8\% \pm 7.6\%$	$30.9\% \pm 10.5\%$	$0.04\% \pm 0.10\%$
	Full (AIM)	$20.5\% \pm 11.0\%$	$22.8\% \pm 7.5\%$	$31.6\% \pm 11.7\%$	$21.7\% \pm 8.2\%$	$0.002\% \pm 0.01\%$
	Full (AI)	$5.5\%\pm7.1\%$	$15.9\% \pm 11.7\%$	$18.2\% \pm 12.0\%$	$58.2\% \pm 23.6\%$	$2.4\% \pm 6.2\%$



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The duration of AIs generally increased as a function of the inducing stimulus contrast (3.8, 5.2, 7.1, 11.0, and 38.6 s for the five contrasts). Although the distribution of percept types was fairly similar across the inducing contrast conditions (for details see Table 1), subjects did see the coherent patterns slightly more often as the inducing contrast decreased (see Fig. 2c, linear trend analysis, t(19) = 5.91, p = 0.000011, d = 1.32, 95% CI [0.29, 0.61]). This suggests that the interocular grouping was in relation with the strength of the retinal signal such that interocular grouping increased with decreased contrast in the stimulus. Even so, subjects reported seeing the coherent patterns with a much higher probability for the FCI AIs than for the lowest-contrast inducers (70.6% vs. 38.6%; t(19) = 5.80, p = 0.000014, d = 1.30, 95% CI [0.20, 0.44]).

Al-mimicking induction: low-pass filtered inducers (Experiment 2b). Eye fixation jitter during induction can blur AIs by shifting the edges of the adaptation region, much like a low-pass filter does^{9,16}. This may cause the retinal rebound signals to be different during AI compared to induction, *e.g.* blur may cause the AIs to contain more energy at lower spatial frequencies. To control for blur, another AI-mimicking experiment was conducted with low-pass filtered stimulus (see Supplementary Fig. S1).

One may argue that in Experiment 2a, the apparent contrast of FCI AIs were not precisely measured for each individual, but instead estimated according to the pilot test in only 2 subjects. Therefore, in this experiment, the apparent contrast of FCI AIs were measured for each subject in a preliminary test. We found that the apparent contrast for FCI AIs ranged between 0.02 ± 0.01 and 0.42 ± 0.16 (for details, see Supplementary Table S2). Thus three levels of the mimicking contrast were individually selected for each subject: the lowest contrast (0.02 ± 0.01), the highest contrast (0.42 ± 0.16), and the medium contrast (0.10 ± 0.02) which was the square root of the product of the lowest and the highest contrasts. Subjects in this experiment were assigned an extra response key to report seeing the grid patterns (Type V). Besides, if the AI at any quadrant(s) was not visible, subjects were instructed to release all keys.

Subjects perceived the coherent patterns much more often for the FCI AIs than during the lowest-contrast inducers (58.2% vs. 41.0%, paired t-test: t(15) = 2.82, p = 0.013, d = 0.71, 95% CI [0.30, 0.42], see Fig. 2e and more details in Table 1. The durations of AIs were 3.1, 7.4, 16.6, and 49.3 s for the four inducing contrasts). As in Experiment 2a, subjects in Experiment 2b also saw the coherent patterns slightly more often as the inducing contrast decreased (See Fig. 2e, linear trend analysis, t(15) = 3.371, p = 0.004, d = 0.8425, 95% CI [0.0372, 0.1651]).

Over time, the perceived contrast of AIs might decrease below the lowest inducing contrast we employed. This would result in more frequent coherent percepts in AIs and potentially account for the difference in percept type between periods of AI and stimulus induction. Therefore, we performed a time course analysis for both the induction and AI data. In each trial, predominance for the types I-IV was computed for each 1-s time bin. As the percepts of type I-IV corresponded to a general increase of interocular grouping, we estimate the subjects' interocular grouping tendency over time. For each time bin, the predominance values for the four types of percepts were multiplied with a contrast vector [1 2 3 4]. The sum of the product was defined as the integration index, with larger positive index corresponding to stronger interocular grouping. The integration indices of each time bin was then averaged across trials for each subject.

According to our preliminary test, the apparent contrast of the FCI AIs in the first few seconds was probably 0.42 ± 0.16 (see Supplementary Table S2 for details), which was much higher than the lowest inducing contrast (0.02 ± 0.01) . If apparent contrast alone determines the degree of interocular grouping, one would expect weaker interocular grouping during the first few seconds of the FCI AI phases than during the lowest contrast induction. However, the results do not support this notion. Instead, the integration indices during the first 3 s of the FCI AI phases were not significantly different from the asymptote of the integration index during the lowest contrast inductions (paired t-test, t(15) = 0.019, p = 0.98, d = 0.0048, 95% CI [0.396, 0.403], see Fig. 2f), suggesting that interocular grouping during the first few seconds of the FCI AI phases was no weaker than during the lowest contrast inductions.

Furthermore, if the gradual decay of AIs increased interocular grouping over time, one would expect to see an increasing slope in the time course of the integration index in AIs. However, no significant increasing trend was observed within the first 20 s of the time course in Experiments 1, 2a and 2b when induced with full contrast (see the red curves in Fig. 2b,d and f, linear trend analysis: Experiment 1: t(9) = 0.67, p = 0.519, d = 0.21, 95% CI [-21.54, 39.69]; Experiment 2a: t(19) = 0.66, p = 0.517, d = 0.15, 95% CI [-10.86, 20.89]; Experiment 2b: t(15) = 1.68, p = 0.114, d = 0.42, 95% CI [-6.08, 51.23]). Therefore, we believe that the decay of AIs cannot account for the stronger interocular grouping during the AIs than during the AIM inductions.

Interocular phase alignment (Experiment 2c). Eye fixation jitter during the induction is never 100% correlated across the two eyes. As a result, the phase alignment of the gratings presented to different eyes will also be unstable. It seems plausible that the stable phase alignment for the interocular patches in the AI condition enhances the effects of interocular grouping for this condition relative to the AIM induction condition. If this is the case, rendering the inducer elements out of phase at the adjacent quadrants in the opposite eye (Fig. 3a) might substantially reduce the proportion of coherent percepts. To answer this question, we conducted Experiment 2c.

AIs lasted for 40.0 ± 14.1 s for the "in-phase" condition and 41.2 ± 38.5 for the "out-of-phase" condition. As shown in Fig. 3b, the two induction conditions produced very similar predominance patterns. A 2 (testing stage: induction vs. AI) × 2 (phase alignment: in-phase vs. out-of-phase) repeated measurement ANOVA on the predominance for the coherent percepts revealed a significant main effect of testing stage (F(1, 11) = 13.85, p = 0.003, d = 1.12), indicating higher predominance of coherent percepts for AIs. However, no significant main effect of phase alignment (p > 0.250) or interaction (p > 0.250) was found. These results suggest that the mechanisms controlling interocular grouping should arise from polarity independent cells. Therefore, disturbed phase alignment during induction cannot account for the enhancement of interocular grouping for the FCI AI condition relative to the AIM induction condition.

Eye movements and Als (Experiment 3). To further rule out eye fixation jitter accounts of our main findings, we recorded participants' eye movements in Experiment 3. AIs are stabilized on the retina, but the inducers are never stabilized due to fixational eye movements. One may argue that the interocular grouping during the inductions was less successful than during the AIs because of the retinal stabilization being more disturbed by fixational eye movements during the inductions than during the AIs. In other words, it is not AI per se but a general effect of eye movement that drives our findings. If this is the case, one would observe a close correlation that more eye movements always correspond with less coherent percepts during the inductions. For this purpose, we computed the correlation between the frequency of coherent percepts and the number of blinks,





saccades, microsaccades, and lengths of drifts. In the lowest contrast induction condition in Experiment 2b, subject could see the grating during $86.1\% \pm 14.5\%$ of the total induction period (55 s), and 5 out of 16 subjects saw the grating less than 80% of the time. Therefore, a slightly higher inducing contrast (0.04) was used in this experiment.

To evaluate the stability of fixation, a 2D Gaussian model was fit to the spatial distributions of the gaze positions during the full contrast induction phases. The position of the fit was centered 0.2286° and 0.0972° away from the fixation point (see Supplementary Fig. S6 and Table S4 for details). The width of the fit was 0.9496° (σ_x) and 0.6907° (σ_y) . These results showed that most subjects maintained steady central fixations (also see Supplementary Fig. \$5).

No significant correlation was observed between the extent of interocular grouping during induction and any of our eye movement indices (number of blinks, 16.02 ± 14.72 , r(10) = -0.46, p = .13; saccades, 54.19 ± 15.34 , r(10) = 0.07, p = 0.83; microsaccades, 53.09 ± 18.57 , r(10) = 0.29, p = 0.36; and length of drifts, 117.05 cm \pm 37.00 cm, r(10) = -0.44, p = 0.15, see Fig. 4a). Correlation coefficients for individual participants are shown in Table 2. In only 1 out of 12 subjects, was the extent of interocular grouping reliably inversely related to the number of blinks. Furthermore, two subjects displayed individually positive correlations between number of blinks/microsaccades and the extent of interocular grouping. Also, no significant correlation was observed between the strength of interocular grouping during the full contrast inductions and any of the eye movement indices (see Supplementary Fig. S2, Table S3). Taken together, fixation jitter during induction does not appear to lead to less interocular grouping in the inducers than in the AIs.

We also re-examined whether our selection of the filtered stimuli in Experiment 2b was appropriate. The results were shown in the Supplementary Figure S7. For each trial of each subject in Experiment 3, we estimated the image on the retina at each time point (i.e. 4 ms for the 250 Hz sampling rate of the eye movement recording) based on the x y coordinates of the eye fixations. These images were superimposed on each other to simulate the blurred adaptation region on the retina. We then performed a pixel-by-pixel correlation analysis between this simulated image and each of the nine possible candidates shown in the Supplementary Figure S1. Specifically, each image array was reshaped into an N by 1 vector. We thereafter ran a Pearson's correlation analysis between every pair of vectors to obtain a 3-by-3 array of the correlation coefficients for the nine candidates. For each subject, the arrays for the 15 trials were averaged to show the average correlation coefficients for the 9 candidate patches. The results of the correlation analysis suggested that we could use either candidate filter in the left two columns of the 3-by-3 array. The filter we actually selected in Experiment 2b happened to be one of them.

Discussion

The present study reports a novel phenomenon that interocular grouping is more prevalent in AIs as compared to inducers. By the comparison with the inducers with AI-similar contrast, the results of Experiments 2a and 2b suggest that lower contrast and blurry appearance of the AIs are not sufficient to account for the enhanced interocular grouping during the AIs. Since AIs are stabilized on the retina, but the AIM inducers are not, the enhanced interocular grouping for the AIs might simply be due to the distinct contribution of eye movements between the two conditions. The results of Experiment 2c suggest that interocular grouping is not dependent on the interocular phase alignment. Therefore, the interocular phase misalignment in the AIM induction condition is not likely to strongly affect the degree of interocular grouping. Experiment 3 further explored the relation between the prevalence of interocular grouping and eye movements. Because no significant correlation was found



Figure 4. Results of Experiment 3 (Eye movements tracking). (a) Correlation between the predominance of type IV percepts and the number of blinks (upper left), microsaccades (upper right), saccades (lower right), and drift length (lower left) across the subjects. Each dot represents a subject. (b) Microsaccadic and saccadic peak velocity–magnitude relationship for all subjects combined. Each dot represents a microsaccade or a saccade with peak velocity indicated on the *y*-axis and magnitude indicated on the *x*-axis. (c) Magnitude distribution of microsaccades and saccades.

	Number	of blinks	Number of	saccades	Number of n	nicrosaccades	Drift le	ength
Subject	r/r _s	p	r/r _s	p	r/r _s	р	r/r _s	p
1	-0.4901	0.0060*	< 0.0001	1	0.2834	0.1291	0.0638	0.7368
2	0.1825	0.3343	0.0474	0.8036	-0.1875	0.3210	-0.0896	0.6378
3	-0.0240	0.8998	0.3203	0.0844	0.0845	0.6569	0.1192	0.5304
4	0.5756	0.0009*	-0.1883	0.3189	-0.2430	0.1957	0.0843	0.6567
5	-0.0634	0.7393	-0.0506	0.7906	-0.0833	0.6615	0.1711	0.3645
6	0.2145	0.2550	0.1019	0.5921	0.3839	0.0362*	-0.1776	0.3477
7	0.0732	0.7005	0.1105	0.5611	0.0092	0.9613	0.1017	0.5916
8	0.1849	0.3280	-0.2338	0.2136	-0.1647	0.3846	0.3359	0.0695
9	-0.0974	0.6086	-0.2430	0.1957	-0.1561	0.4099	0.0392	0.8372
10	0.0855	0.6533	-0.1680	0.3750	-0.1610	0.3955	-0.0085	0.9645
11	-0.0957	0.6148	-0.2046	0.2782	0.3381	0.0677	-0.1881	0.3195
12	-0.0289	0.8795	-0.2567	0.1708	-0.0772	0.6851	-0.2980	0.1098

Table 2. Correlation between the predominance of coherent percepts and eye movement indices. We performed Pearson product-moment correlation analyses if the original or square-rooted/logarithmic data were normally distributed. Otherwise, we computed Spearman's rank correlation analyses (see those shown in italic). Significant correlations are shown in bold.

between the eye movement measures and interocular grouping, our observed effects do not appear to be due to unbalanced influences of eye movements on the AIs and inductions. However, caution is warranted when making a conclusion based on negative results. Therefore, more extensive future work is needed to fully test the eye movement argument.

Our work lends new support to the hypothesis that AI formation at least partially results from cortical adaptation. The results also go against predictions derived from Zaidi *et al.*'s retinal generation account which hold that interocular grouping in FCI AIs should be no stronger than during the presentation of AIM inducers. The FCI AIs and AIM inducers are similar in local appearance, and therefore, their respective cortical output signals are presumably similar in strength^{17–19}. Following adaptation to full contrast, neural gains of the thalamic

FCI AI:

Visual pathway strongly adapted to high contrast





Figure 5. Schematic diagram showing the retinal and cortical activity profile for the FCI AI (upper) and AIM inducer (lower) conditions. Based on the assumption that the retinal generation notion is true and the results in Experiment 2 (lower contrast producing more interocular grouping) hold, one would predict that more frequent monocular patterns would be perceived in the FCI AIs than in the AIM inductions, as denoted by the larger green arrow and smaller red arrow for the FCI AI condition than for the AIM inducer condition. However, the prediction contradicted the actual observations. Thus, the retinal generation notion is denied. More detailed deductions are given in the discussion.

and cortical cells in the FCI AI condition are substantially reduced^{20,21}. However, this is not the case during the AIM induction for which the adapting contrast is low^{22} . If the retina is the only origin of AI signals, as stated in Zaidi *et al.*'s retinal generation account, comparable cortical outputs between the two conditions would require stronger retinal signals for the FCI AIs than for the AIM inducers. However, a stronger retinal signal should if anything lead to stronger monocular neuronal activities in the FCI AI condition (for simplicity, the thalamic signals are not discussed).

In Experiment 2, the coherent percepts during the induction decreased as the inducing contrast increased. This result indicates that stronger eye-based grouping²³⁻²⁵ and (or) weaker pattern-based grouping^{23,26-29} correlate with stronger retinal and (or) cortical output signals. One would thus predict less coherent percepts in the FCI AIs if retinal signals determine grouping, because most likely the retinal signal is stronger in the FCI AIs than the AIM inductions. Alternatively, one may predict roughly an equal amount of predominance between the FCI AIs and AIM inductions if the summed cortical signal mainly determines grouping (Fig. 5 also assists in illustrating the deductions). However, we found much more coherent percepts for the FCI AIs than for the AIM inducers. This suggests that AI formation should also involve cortical mechanisms, and that there are likely multiple sources for AI signals in the visual system. Presumably, these cortical sources for AI signals might derive from rebound responses of cortical neurons after adaptation, and is an open question that may be tested in future work.

So what caused the increased interocular grouping in the AIs? According to the hybrid model of binocular rivalry²³, coherent percepts should be caused by pattern-based grouping^{26–29}, but disturbed by eye-based grouping that facilitates the perception of monocular patterns^{24,25}. During the AIM induction, the retina is the unique source of the input signals. However, for the FCI AIs, the input signals (*i.e.* AI signals) are generated from multiple sites along the visual pathway. Many of these cortical signal origins may be binocular neurons representing the pattern-based grouping. Thus the probability of pattern-based grouping may be higher in the FCI AI condition than in the AIM induction condition, leading to more coherent percepts in the former.

There have been reports of differences in adaptation properties between monocular and binocular cells, suggesting substantially less adaptation in binocular cells over monocular cells^{30–32}. One possibility then is that the high contrast stimuli of the present study particularly reduced monocular gain, but left binocular cells rather unaffected. During the afterimages, monocular cells may have adapted while binocular cells were spared and still responded vigorously. One caveat with this line of reasoning is that binocular cells receive their inputs from monocular cells^{33,34}, and that their responses may correspond to the mean of the monocular cells³⁰. As monocular cells adapt and reduce their gain, binocular cells will receive correspondingly weaker signals and in turn become less excited. Therefore, a slightly more complicated arrangement of interaction between monocular and binocular

cells is required to account for the present findings. Certainly, further investigation is required to resolve the circuitry underlying the perceptual result reported in this study.

It should be noted that a previous study by Klink and colleagues found that over prolonged exposure to binocular rivalry images, the perception of mixtures of the two monocular images became more prevalent³⁵. Broadly speaking, both this and our work suggest that adaptation to binocular rivalry images can lead to increased binocular integration. However, their findings differ from ours in a few important aspects. Firstly, the two studies are believed to reflect different kinds of binocular integration. The mixed percepts in Klink et al.'s³⁵ work are either piecemeal mixtures or superimpositions of the monocular patterns. Piecemeal perceptions were usually composed of an uncertain amount of randomly distributed patchwork-like zones of local monocular dominance in their study. The stable percepts in our work could be systematically categorized into four fixed regular types (see Fig. 1). The formation of these four types of percepts should be subject to the mechanisms of perceptual grouping, obeying the Gestalt theory of perception³⁶, e.g. collinearity³⁷. Secondly, it is very unlikely that Klink et al.'s³⁵ effect accounts for our results. The accumulation of Klink et al.'s³⁵ effect strongly relies on the constant eye-of-origin information of the rival images. However, the eye-of-origin information of the rival patterns in our study was randomized across the trials. Also, the adaptation duration in each trial was only 55 s, while in Klink et al.'s³⁵ work it was 35 min. Thirdly, the main finding in the current work is about the enhanced interocular grouping in the AIs relative to the inducers. However, Klink et al. did not investigate AIs³⁵, thus their work provides no information about AIs.

The present study supports the view that cortex is directly involved in the generation of AI signals by showing distinct interocular grouping for AIs and physical stimuli of similar appearance. Binocular rivalry is considered to occur at multiple stages of visual processing^{26,38–43}. The observed phenomenon suggests that perceptual alternations in binocular rivalry may depend on both the early feed-forward signals and later controlling mechanisms that favor pattern coherency such as binocular neurons.

Methods

In all the experiments of the present study, all participants had normal or corrected-to-normal vision. Experimental procedures were approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences, and all methods were performed in accordance with the relevant guidelines and regulations. Informed consents were obtained from all the subjects in all the experiments of the present study.

Experiment 1. *Subjects.* 10 naïve subjects (6 males, ages ranging from 21 to 26 years) participated in this experiment.

Apparatus. Stimuli were presented on a gamma-corrected 27-inch Asus VG278HE LED monitor (1920 pixel \times 1080 pixel resolution at the refresh rate of 120 Hz) in a dark room. Subjects viewed the display at a distance of 100 cm through a pair of shutter goggles (Nvidia 3D vision wireless glasses) that alternated between left and right eye occlusion with each frame. A chin-rest was used to minimize head motion. The display was calibrated with a Photo Research PR-655 spectrophotometer. To calibrate the display, we measured the luminance gamma curves and inverted them using a look-up table. The mean luminance of the screen was 57.4 cd/m².

Stimuli. Stimuli in each eye contained a centrally presented 2×2 square array of sinusoidal gratings (full contrast, 1 cyc/deg), with each grating subtending 3° (see Fig. 1). A black-and-white frame (7° × 7°, width: 0.09°) surrounded each square array to aid fusion. Presented to one eye, the elements in two diagonal quadrants were vertical gratings, while those in the other quadrants were horizontal. The orientations of the corresponding elements in the other eye were orthogonal, thus binocular rivalry could happen at each element position. Theoretically, complete interocular grouping might produce a coherent percept of an all-vertical or all-horizontal grating. With incomplete grouping, subjects may perceive two types of partially integrated patterns to avoid having them see the monocular grating arrays. The four possible types of percepts are listed in the lower right part of Fig. 1. The stimuli remained constant within each trial, with the spatial phases reversed across trials. The stimulus pattern and its eye of origin were randomized across trials. All stimuli were presented foveally on a mid-gray background with a red bull's eye central fixation point (0.36° in diameter).

Procedure. At the beginning of each trial, dynamic white noise $(6^{\circ} \times 6^{\circ})$ was presented for 3 s to minimize any residual afterimage from the previous trial. The induction in each trial lasted for 55 s. During both the induction and AI phases, subjects were told to maintain fixation and report which of the four types of patterns they saw by pressing and holding one of the four arrow keys. They were also told to release all the keys for the last 2 s in the induction phases following a beep cue, in case the final response in the induction phases conflicted with the initial response in the AI phases. During both the induction and AI phases, subjects sometimes experienced perceptual alternations of patterns defined as the same type in Fig. 1. For example, it was common for them to see rivalrous all-vertical and all-horizontal AIs. However, we did not assign additional keys to distinguish between these within-type perceptual alternations as it could have introduced confusion, and the focus of the study did not warrant that level of precision in the data. Once the induction ceased, subjects were presented with a mean field excepting the fusion frames and fixation point which remained on the screen. Als have been found to fluctuate in visibility before they finally cease to be visible^{44,45}. To acquire sufficient data during the AI phases, we instructed subjects to close their eyes for 2 s and then reopen the eyes whenever the AIs intermittently disappeared. This would allow the AIs to reappear, though they would be fainter each time they reappeared. Subjects were told to stop a trial by pressing the spacebar when they had closed and reopened the eyes for three times but still could not make the AIs reappear. After a brief practice period explained below, each subject completed 15 trials.

Using four arbitrary keys to indicate percept type is potentially confusing, and incorrect use of the keys naturally disqualifies the results. To reduce the risk of percept-to-key mapping errors, all subjects were required to practice the task in two successive stages. In the first stage of practice, binocularly congruent grating patterns were presented to them, which simulated all the possible percepts of the four categories. This stage terminated once the subjects had made no incorrect responses over 6 continuous minutes. Thereafter the second stage started, in which they viewed dichoptic stimuli as in the formal experiment. Taken together, the practice would substantially have limited the risk of incorrect response mapping and ensured that our subjects fully understood and used the four categories to complete the task.

Experiment 2a. *Subjects.* Twenty subjects (7 males, ages ranging from 19 to 34 years) participated in Experiment 2a. Two of them had participated in Experiment 1. Nineteen of them were naive to the experimental hypotheses.

Stimuli and procedure. Experimental parameters were the same as in Experiment 1 except for the following changes. Stimuli were presented on a gamma-corrected 22-inch Dell P1230 CRT monitor (1024 pixel \times 768 pixel resolution at 85 Hz), which was driven by a Bits# 14-bit video card (Cambridge Research Systems). Stimuli were viewed at a distance of 88.5 cm in a dark room through a mirror stereoscope. The mean screen luminance was 51.9 cd/m². The fusion frames were removed during the AI phases as they might reduce the visibility of AIs especially when the inducing contrast was low.

In a separate preliminary test, one author and one naïve subject empirically measured the apparent contrast of FCI AIs. See the Results section for more details.

In each block of the formal experiment, subjects completed 24 trials for each of the test contrasts. In total, 10 blocks (120 trials) were completed, with the sequence of the five testing contrasts counterbalanced across subjects using Latin square series.

Experiment 2b. *Subjects.* Seventeen subjects were recruited (8 males, ages ranging from 18 to 29 years). One of them was excluded because he could only see the lowest contrast inducer 14.3% of the induction duration, whereas the other subjects saw the lowest contrast inducer $86.1\% \pm 14.5\%$ of the inducer duration. All subjects were naive to the experimental hypotheses.

Stimuli and procedure. The details of this experiment were the same as Experiment 2a except for the following. The full contrast inducer was identical to that of Experiment 2a. However, the lower contrast inducing grating arrays were filtered with a modified 3rd-order Butterworth filter (cutoff at 1 cyc/deg), to retain the energy for spatial frequencies lower than 0.5 cyc/deg. The reason for using the filter was to reduce the energy of higher frequency components as much as possible while avoiding severe distortions of the image (see Supplementary Fig. S1). To revive AIs, instead of requesting blinks, a 1-s display containing a black screen was adopted. This reduced the unnecessary blinks during the AI phases. If no responses were made within 3 s after a black screen, another black screen would be presented. If the AIs still would not reappear after 3 successive black screens, subjects ended the current trial by pressing a specified key.

Because the authors sometimes perceived plaids while piloting the test, and since that perception did not fit into the four perceptual categories used in the previous experiments, subjects in this experiment were assigned an extra response key for reporting plaids. Type V represents the perception of a plaid. Besides, if the AI at any quadrant(s) disappeared, subjects were instructed to release all the keys.

As in Experiment 2a, subjects completed a separate preliminary test to measure the apparent contrast of FCI AIs. In contrast to Experiment 2a, this test was now taken by each subject. The test involved a total of 5 trials. The contrast for the point of subjective equality ranged between 0.02 ± 0.01 and 0.42 ± 0.16 (for details, see Supplementary Table S2). Here 1 represented the full contrast. Three levels of the mimicking contrast were individually selected for each subject: the low and high contrasts were the lowest (0.02 ± 0.01) and highest perceived contrasts (0.42 ± 0.16) during the AI phases. Furthermore, a medium contrast was computed by taking the square root of the product of the lowest and highest contrasts which yielded an average of 0.10 ± 0.02 .

Experiment 2c. *Subjects.* Twelve subjects (8 males, with an age range from 20 to 25 years) participated in Experiment 2c. All of them were naive to the experimental hypotheses.

Stimuli and procedure. Each subject completed two sessions. In one session, the stimuli and procedure were identical to those of Experiment 1. Since each grating element contained three full sinusoidal cycles, there was a unified spatial phase everywhere on the coherent pattern under perfect interocular grouping. Subjects could also perceive a coherent AI pattern with a single spatial phase. We term this induction condition the "in-phase" session.

In the other session, the grating elements of two diagonal quadrants in one eye were out of phase with those of the two opposite diagonal quadrants in the other eye (See Fig. 3a). When coherent AI patterns were perceived, this stimulus arrangement lead to perception of patterns in which the spatial phase in each quadrant was reversed with respect to those of the adjacent quadrants. We call this condition the "out-of-phase" session.

Experiment 3. *Subjects.* One author (M.B.) and 13 naive subjects (7 males, ages ranging from 20 to 36 years) participated in this experiment. One of them also participated in Experiment 2b. All subjects had normal or corrected to normal vision. Two subjects' data sets were removed from further analysis because the proportions of valid eye movement data were less than 85%.

Stimuli and procedure. Experimental parameters were the same as in Experiment 2b except for the following changes. The AI-mimicking inducers with 0.04 contrast were tested in this experiment, and the grating arrays were also low-pass filtered as in Experiment 2b. In total, subjects completed six blocks, each block containing five trials. Gaze calibration was performed at the beginning of each block. Throughout a block, subjects were required to keep their heads still on the head and chin-rest. A short rest period was given after the end of each block. Subjects also completed 15 extra trials with full contrast induction as in Experiment 1 in a separate session with eye tracking. The behavioral results confirmed that the basic effects existed in these subjects (the predominance for the coherent precepts was higher for the AIs (54.4%) than for the inducers (19.8%), t(11) = 5.10, p = 0.00034, d = 1.48, 95% CI [0.20, 0.49]).

Eye movement recording. Eye movements for both eyes were recorded using a fast video-based eye movement monitor (SMI RED250, temporal resolution 250 Hz, instrument noise 0.03 deg RMS) in its off-the-shelf configuration. The eye tracker was positioned between the CRT monitor and stereoscope. The stereoscope was installed with cold mirrors that were transparent to infrared light, allowing for tracking eye movements through the stereoscope. Gaze calibration was performed using the conventional nine-point calibration routine.

Eye movement analyses. Blink. When blinks occur, the eye-tracker will lose track of the pupil information, which usually produces missing samples during the recording. However, errors in data acquisition may also cause missing samples. To differentiate blinks from acquisition errors, we adopted two criteria for blink detection. Firstly, the minimum duration of missing samples caused by blinks should be no shorter than 12 ms. Secondly, the interval between any two successive detected blinks must be no shorter than 300 ms (see Supplementary Fig. S3b). With these criteria, the instant and frequent missing samples due to acquisition errors could be distinguished from blinks and were thus removed (frequency for missing samples due to acquisition errors amounted to $0.066\% \pm 0.069\%$ of the full contrast induction period and $0.076\% \pm 0.114\%$ of the AI-mimicking induction period. As shown in Supplementary Fig. S4, most missing samples of this type occurred for a single or two continuous samples, *i.e.* 4 or 8 ms in duration).

Saccades and microsaccades. When identifying saccades or microsaccades, we first rejected the portions of data in which blinks or semi-blinks occurred, as well as data sampled 200 ms before and after blinks⁴⁶. Data with very fast decreases or increases of pupil area ($>7.90 \text{ mm}^2$ /sample or 50 pixel²/sample) were deemed as semi-blinks where the pupils were never fully occluded⁴⁶. A 4th-order Savitzky-Golay filter with a 156 ms window (39 data points) was then used to reduce the noise⁴⁷.

After these preprocesses, microsaccades and saccades were automatically detected by using a velocity-based algorithm⁴⁸. First, the velocity for each fixation position was calculated based on the time series of fixation positions, which produced a distribution in the 2D velocity space (see Supplementary Fig. S3d). Second, saccades were defined when the velocity was more than four times the median-based SD of the velocity distribution (λ =4) and when its duration was larger than 24 ms. In addition, to avoid defining potential overshoot corrections as new saccades, only intersaccadic intervals longer than 20 ms were retained for analysis⁴⁹. Finally, saccades less than 1° in magnitude were considered to be microsaccades (see Supplementary Fig. S3c).

Drift. Involuntary drifts of the eyes were defined as motion in the remaining periods excluding saccades, microsaccades, and blinks⁵⁰. Periods of semi-blinks were also excluded. The lengths of drifts were calculated using the sum of the eye position shifts during all the drifting periods. Bear in mind that drift lengths thus assessed are also influenced by tremors and instrument noise.

For each eye, we analyzed the number of blinks, saccades, microsaccades, and lengths of drifts in each trial. For each subject, these indices were averaged across the two eyes. Thereafter, we conducted correlation analyses between the predominance of coherent percepts and each eye movement index. After averaging the eye movement indices across trials for each subject, we also conducted similar correlation analyses across the subjects. A Pearson product-moment correlation (r) analysis was performed if the distributions of the original or transformed data were normal (square root-transformation for the number of blinks, microsaccades, and saccades; logarithmic transformation for the drift length and predominance of type IV percept). Otherwise, a Spearman's rank correlation (r_s) was computed.

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Author Contributions

M.B. conceived the study after first observing the phenomenon. B.D. and M.B. designed the experiments. B.D. collected the data. B.D., M.B. and L.H. analyzed the data. M.B. and L.H. wrote the paper.

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Interactive effect of motivational motor action and emotion on divergent thinking



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ABSTRACT

The present study aimed to investigate the integrated effect of approach/avoidance motor action and emotion on divergent thinking. A total of 115 participants were randomly assigned to one of the four experimental conditions (i.e., approach-positive, approach-negative, avoidance-positive and avoidance-negative). Participants' emotion was induced by videos. They were then asked to solve two Alternative Uses Tasks (AUT) while performing motivational motor action (i.e., arm flexion or extension). Results showed that approach motor action (i.e., arm flexion) engendered more ideas than avoidance motor action (i.e., arm extension). More importantly, participants in approach-negative condition performed better on AUT than those in approach-positive condition. In the same vein, avoidance-positive condition promoted divergent thinking in contrast to avoidance-negative the incongruence of motivational motor action and emotion enhances divergent thinking. The experience of novel contexts resulted from such incongruence may account for the benefits.

1. Introduction

Creativity is generally conceived as the ability to generate novel and useful ideas, insights, or problem solutions (Amabile, 1983; Sternberg & Lubart, 1999). As a key component of creativity, divergent thinking (DT) is a facet of cognition that leads in various directions (Runco & Acar, 2012). It is usually referred to as a thought process used to generate original ideas by exploring diverse possible solutions, which is involved in many creative efforts (Kaufman, Plucker, & Baer, 2008; Runco & Acar, 2012). Therefore, factors influencing DT have received a lot of attention in creativity research. One critical predictor is the type of goals that drives individuals' behaviour. Goals include approaching positive stimuli or avoiding negative stimuli. Approaching positive outcomes (approach motivation) and avoiding negative outcomes (avoidance motivation) can exert various effects on DT (Friedman & Förster, 2000, 2002, 2005; Hao, Yuan, Hu, & Grabner, 2014).

1.1. Approach and avoidance motivation with DT

Approach motivation refers to the behaviour tendency energized by positive stimuli, whereas avoidance motivation refers to the behaviour tendency energized by negative stimuli (Elliot & Covington, 2001). They are crucial to successful adaptation: avoidance motivation facilitates surviving, while approach motivation facilitates thriving.

A large body of studies has shown that approach motivation enhances DT whereas avoidance motivation blocks it (Friedman & Förster, 2000, 2002, 2005; Hao et al., 2014; Mehta & Zhu, 2009). For example, Friedman and Förster (2002) found that arm flexion associated with approach motivation engendered better DT than arm extension associated with avoidance motivation. According to Cacioppo, Priester, and Berntson (1993), over the course of lifetime, individuals repeatedly flexed their arms to acquire desired objects (i.e., approach motivation). On the other hand, individuals repeatedly extended their arms to reject undesired objects (i.e., avoidance motivation). Thus, arm flexion is considered as an approach motor action whereas arm extension as an avoidance motor action (Cacioppo et al., 1993; Friedman & Forster, 2010, 2002). Approaching appetitive objects signals a benign environment, while avoiding aversive objects signals a dangerous environment. As a result, encouraged by a benign environment clue, individuals tend to adopt heuristic strategies that benefit creative thinking. However, individuals who encounter a dangerous situation usually adopt systematic strategies, which are harmful to DT (Friedman & Förster, 2002, 2005; Hao et al., 2014).

Though researchers found approach motivation improved DT in comparison to avoidance motivation, other researchers demonstrated that persistent and systematic thinking style underlying avoidance

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motivation may also facilitate DT. Avoidance-motivated individuals are easier to feel fatigue. However, they would put more effort into the task if they conceived the task as functional for the next task, which promoted DT (Roskes, De Dreu, & Nijstad, 2012). Moreover, Icekson, Roskes, and Moran (2014) have argued that optimism can mediate the undermining effect of avoidance on DT by mitigating negative emotion. Therefore, it is possible that the systematic processing underlying avoidance motivation could bring about better DT when more effort was exerted or negative emotion was attenuated.

1.2. Approach/avoidance motivation, emotion, and DT

Approach/avoidance motivation and emotion are correlated with each other. Emotions involve multiple distinct processes including affect, appraisal of the valence of a stimulus (its goodness or badness), physiological arousal, and some sort of subjective feelings (Ellsworth, 1994). These correlated processes are posited to operate in parallel. The dissociability of these components lends credence to the possibility that some subset of them can be triggered without coactivating the "subjective feeling" component (Friedman & Forster, 2010). Approaching rewards or avoiding noxious objects signals safety or danger, leads to the appraisal of goodness or badness (Cacioppo et al., 1993). Thus, approach/avoidance motor action can be viewed as implicit affective cues by appraising the goodness or badness of the environment (Friedman & Forster, 2010).

In addition, according to Regulatory Focus Theory, both approachavoidance behaviour and emotional sensitivities are parts of promotion/prevention motivation system (Higgins, 1997). To fully understand the psychological quality of emotions, promotion or prevention focus must be considered (Cacioppo, Gardner, & Berntson, 1999). Specifically, when individuals successfully reach the appetitive ends, they can have positive emotions such as happiness. Failing to reach appetitive ends leads to negative emotions such as sadness. Likewise, successfully avoiding aversive stimuli leads to positive emotions such as ease or calm, whereas failing to avoid aversive stimuli evokes negative emotions such as fear. Taken together, it is interesting to investigate how implicit emotional cues (i.e., approach/avoidance motor action) and explicit emotions shape DT.

Within the emotion-DT literature, most researchers have distinguished emotion in terms of valence and activation/arousal. De Dreu, Baas, and Nijstad (2008) have developed a dual pathway to creativity model to understand emotion's influence on DT. This model accounts for the joint mood activation and mood valence effect on DT. According to the model, activating moods (e.g. angry, fearful, happy, elated moods) facilitate creative performance through enhanced cognitive flexibility when the tone is positive or through enhanced persistence when the tone is negative. That is, mood activation determines the likelihood of DT, while valence determines the routes by which DT comes out (flexibility route or perseverance route). Recently, researchers have distinguished emotions in terms of valence, activation and orientation (Baas, De Dreu, & Nijstad, 2011; Yeh, Lai, & Lin, 2016). Orientation indicates whether the emotional states focus on approaching rewards or avoiding threats. For example, Gasper and Middlewood (2014) have found that respondents in approach-oriented states (elated) performed better on making creative associations than those in avoidance-oriented states (distressed).

1.3. The present study

Taken together, both motivational motor action and emotion share the same attribute of orientation (approach vs. avoidance). Meanwhile, both are predictors of DT. Though arm motor actions associated with approach/avoidance are not capable of inducing explicit emotions (Friedman & Förster, 2000, 2002), they may occur simultaneously with situations inducing emotions such as happiness or fear during creative ideation. However, it is still unknown how these two factors interact during DT.

To investigate this question, participants in this study were asked to watch a 2-minute video to induce positive/negative emotions. Afterwards, they completed the DT task while performing arm flexion (approach motor action) or extension (avoidance motor action). Efforts of executing the arm motor actions and the enjoyment of task were measured to rule out the potential contaminant effects of these variables on DT. We were interested in the question whether the interaction between motivational motor action and emotion could promote DT. We were not able to make exact prediction for the following reasons. On the one hand, motivational motor action combined with emotion may promote DT. That is, approach motor action combined with positive emotion may lead to higher DT than other combinations of motivational motor action and emotion. On the other hand, motivational motor action may interact with emotion during creative thinking. That is, approach motor action with negative emotion, or avoidance motor action with positive emotion could promote DT.

2. Method

2.1. Participants and design

A total of 115 college students participated in the experiment. A 2 (Motivational Motor Action: approach motor action vs. avoidance motor action) \times 2 (Emotion: positive emotion vs. negative emotion) between-subject design was employed. Participants were randomly assigned to one of the four experimental conditions. The data of 7 participants were excluded from further analyses, because these participants did not observe the instruction of thinking ideas that are both novel and useful. Based on evaluation of raters, their ideas were not of usefulness at all. Thus, the final sample consisted of 108 participants (85 females, 23 males; age ranged from 18 to 28 years old, M = 22.05, SD = 2.56). There were 26, 28, 26, 28 participants in the approachnegative, approach-positive, avoidance-negative, and avoidance-positive conditions respectively. Results of Pearson Chi-square test showed no difference in gender ratios among four conditions, $\chi^2 = 0.54$, p = .91. All participants were right-handed and native speakers of Chinese. They gave written informed consent prior to the experiment and received approximately 5 US dollars for their participation. The protocol of the experiment was approved by the Institutional Ethics Committee at East China Normal University.

2.2. Procedure

Upon arrival, participants were seated at a table approximately 29.5 in. in height. An instruction sheet with a cover story was provided to them, similar as what used in previous studies (Friedman & Förster, 2000, 2002):

"Today, you will be participating in a study examining the effects of hemispheric lateralization on problem solving. We are trying to understand the relationship between left and right brain activation and the ability to solve certain type of problems. Basically, there is an on-going debate, with some people saying that the left hemisphere is the centre for this type of cognitive activity and others saying that the right hemisphere is more critical."

Following the cover story, participants were asked to watch videos to induce emotions (see details in Emotion inductions). Then, participants were informed that he or she had been randomly assigned to the left hemisphere activation condition. They were required to assume a particular right arm position. The experimenter demonstrated how to perform arm flexion or extension. A computer screen was placed on the table, and two foam balls were fixed on the top and the underside of the table. In arm flexion condition, a participant's right elbow was bent (Friedman & Förster, 2002), with the palm upward holding the ball on the underside of the table (see panel A in Fig. 1). In arm extension



Fig. 1. Illustrations of arm flexion (A) and arm extension (B). Arrow indicates the orientation of arm to the palm ball.

condition, the right elbow was stretched forward with the palm lightly downward holding the ball on the top of the table (see panel B in Fig. 1).

While flexing or extending arms, participants were asked to solve two AUT problems (i.e., a brick and chopsticks) in 10 min (5 min/ problem), with a 1-min break between the two problems. They were encouraged to try their best to produce ideas that would be thought of by no one else, as suggested by Harrington (1975).

2.3. Emotion inductions

As in previous studies, 2-minute videos were used to induce emotions (Forgas & East, 2008; Hao, Xue, Yuan, Wang, & Runco, 2017). The positive and negative emotion-appropriate video clips were excerpted from comedy and horrible movies respectively. Prior to and immediately after the induction, participants' self-rated emotional states were measured by means of the Self-Assessment Manikin separately (Bradley & Lang, 1994), ranging from 1 to 9 (valence: 1 = very unpleasant, 9 = very pleasant; arousal: 1 = not exciting at all, 9 = very exciting).

2.4. Materials and measures

2.4.1. Experimental task

The AUT was used as the experimental task. It requires respondents to generate as many unusual or original uses as possible for common objects. It is a well-established test of creative potential (Guilford, 1967; Runco & Mraz, 1992). Performance on this task has been demonstrated to be a reliable predictor of actual, real-world creative performance (Runco & Acar, 2012).

2.4.2. Assessment of AUT performance

DT performance was evaluated in terms of fluency, originality and flexibility (Guilford, 1967; Runco & Pritzker, 1999). First, *fluency* was determined by counting the number of non-redundant ideas generated by each participant. Secondly, *originality* was determined by statistically infrequence of responses. To assess it, all ideas were collected into a comprehensive lexicon. Synonyms were identified and ideas collapsed accordingly. The responses scored "1" if they were statistically infrequent (i.e., if 5% or fewer participants in the sample gave the response). All other responses scored "0". Following this scoring procedure, two trained raters independently assessed the originality of all ideas for each participant. The inter-rater agreement was satisfactory (Cronbach's alpha coefficient = 0.79). Finally, two trained raters rated *flexibility* of each idea. *Flexibility* was defined as the categories all ideas belonged to. The raters independently categorized all ideas into 7 to 10

categories. The internal consistence of the two raters was satisfactory (Cronbach's alpha coefficient = 0.74). The fluency, originality and flexibility ratings from two raters were averaged into a single score for each participant.

2.4.3. Post-experiment tests

After completing the experiment, participants' effortfulness of maintaining the arm motor actions was measured by asking them "how effortful was it to maintain the arm flexion or extension?" on a scale ranging from 1 (*not at all effortful*) to 9 (*very effortful*). In addition, their enjoyment of AUT was measured by asking: "How do you like to solve AUT in this experiment?" on a scale ranging from 1 (*not at all*) to 9 (*very much*).

3. Results

3.1. Manipulation checks of emotion induction

Two-way ANOVAs with Emotion (negative vs. positive) and Induction (pre-inducing vs. post-inducing) as between-subject factors were performed on the valence and arousal level of emotion separately.

Results showed significant main effects of Emotion and Induction on valence, F(1, 106) = 6.04, p < .05, $\eta_p^2 = 0.05$; F(1, 106) = 84.48, p < .001, $\eta_p^2 = 0.44$. In addition, the interaction effect of Emotion × Induction was significant, F(1, 106) = 22.51, p < .001, $\eta_p^2 = 0.18$. Specifically, as shown in Table 1, participants with negative emotion felt less delightful after watching the video than that before watching it, t(51) = -6.36, p < .001, Cohen's d = -1.78. In contrast, participants with positive emotion showed more delightfulness than that before the induction, t(55) = 3.83, p < .001, Cohen's d = 1.03.

Results also revealed significant main effects of Emotion and Induction on the arousal, *F* (1, 106) = 18.40, p < .001, $\eta_p^2 = 0.13$; *F* (1, 106) = 5.32, p < .001, $\eta_p^2 = 0.13$. Moreover, significant interaction effect between Emotion × Induction was found, *F* (1, 106) = 55.24, p < .001, $\eta_p^2 = 0.34$. Specifically, as displayed in

Table 1

Emotional valence and arousal before and after induction.

	Emotion	Pre	Post	t	Cohen's d
Valence Arousal	Positive Negative Positive Negative	5.48 ± 1.44 5.67 ± 1.76 4.94 ± 1.83 4.76 ± 1.53	$\begin{array}{r} 6.13 \ \pm \ 1.54 \\ 3.58 \ \pm \ 2.09 \\ 5.73 \ \pm \ 1.70 \\ 7.23 \ \pm \ 1.57 \end{array}$	3.83*** -6.36*** 3.58** 8.42**	1.03 -1.78 0.97 2.36

** p < .01.

*** p < .001.

Table 1, the arousal of participants with negative emotion was higher after induction than that before induction, t (51) = 8.42, p < .01, Cohen's d = 2.36. Similarly, participants with positive emotion showed higher arousal after induction than that before induction, t (55) = 3.58, p < .01, Cohen's d = 0.97.

3.2. Motivational motor action and emotion's effect on divergent thinking

Three two-way ANOVAs, with Action (arm flexion vs. arm extension) and Emotion (positive vs. negative) as between-subject factors, were conducted on the fluency, originality and flexibility scores, respectively.

With respect to fluency, results revealed a significant main effect of Action, F(1, 104) = 4.83, p < .05, $\eta_p^2 = 0.04$. Participants with arm flexion generated more ideas (M = 8.47, SD = 4.30) than those with arm extension (M = 7.08, SD = 2.82). Also, a significant interaction effect of Action × Emotion on fluency was observed, F(1, 104) = 11.02, p < .01, $\eta_p^2 = 0.10$.

Specifically, in the arm flexion condition, participants with negative emotion (M = 9.98, SD = 4.55) showed higher fluency than those with positive emotion (M = 7.70, SD = 3.60), t (52) = 32.62, p < .05, Cohen's d = 0.73. However, in the arm extension condition, participants with negative emotion showed lower fluency (M = 6.29, SD = 2.80) than those with positive emotion (M = 7.82, SD = 2.68), t (52) = -0.2.01, p < .05, Cohen's d = -0.56 (see Fig. 2).

For originality, marginally significant main effect of Action was observed, F(1, 104) = 3.12, p = .08, $\eta_p^2 = 0.03$. Participants with arm flexion (M = 3.89, SD = 2.91) showed higher originality than those with arm extension (M = 3.10, SD = 1.97). In addition, a significant interaction effect of Action × Emotion was found, F(1, 104) = 5.48, p < .05, $\eta_p^2 = 0.05$. As shown in Fig. 3, in the arm flexion condition, participants with negative emotion showed higher originality (M = 4.73, SD = 3.35) than those with positive emotion (M = 3.11, SD = 2.22), t(52) = 2.12, p < .05, Cohen's d = 0.59. However, in the arm extension condition, there was no significant difference in originality between participants with negative emotion and those with positive emotion, t(52) = 1.06, p > .05 (see Fig. 3).

For flexibility, results showed a significant interaction effect of Action × Emotion, F(1, 104) = 6.88, p < .05, $\eta_p^2 = 0.06$. In the arm flexion condition, participants with negative emotion showed higher flexibility (M = 5.36, SD = 1.27) than those with positive emotion (M = 4.46, SD = 1.45), t(52) = 2.43, p < .05, Cohen's d = 0.67. However, in the arm extension condition, there was no difference in flexibility between participants with negative emotion and those with positive emotion, t(52) = 1.32, p > .05 (see Fig. 4).



Fig. 2. Alternative Uses Task (AUT) fluency in different conditions. Error bar indicates standard errors of the mean.



Fig. 3. Alternative Uses Task (AUT) originality in different conditions. Error bar indicates standard errors of the mean.



Fig. 4. Alternative Uses Task (AUT) flexibility in different conditions. Error bar indicates standard errors of the mean.

3.3. Effects of motor action effort and task enjoyment on divergent thinking

To examine the possible effect of motor action effort and task enjoyment on divergent thinking, independent *t*-tests were conducted. Motor action effort and task enjoyment showed no difference between arm flexion and extension, t (106) = 0, p > .05; t (106) = 1.90, p > .05. In addition, a series of correlation analyses showed that motor action effort was unrelated to originality, fluency and flexibility (ps > 0.05). Similarly, results showed no significant correlation between the task enjoyment and originality, fluency and flexibility (ps > 0.05).

When effort and task enjoyment were entered into the above ANOVA models as covariates, the main effect of Action on fluency remained significant (p < .05, $\eta_p^2 = 0.04$); the main effect of Action on originality remained marginally significant (p = .08, $\eta_p^2 = 0.03$); the interaction effects of Action × Emotion on originality (p < .05, $\eta_p^2 = 0.05$), fluency (p < .01, $\eta_p^2 = 0.10$), and flexibility (p < .05, $\eta_p^2 = 0.06$) remained significant.

4. Discussion

The present study investigated the effect of motivational motor action and emotion on DT. In line with our latter prediction, results showed an interaction effect of these two factors on DT. Specifically, arm flexion with negative emotion engendered higher DT in terms of originality, fluency and flexibility. Similarly, arm extension with positive emotion brought about better performance on DT in terms of fluency. Taken together, the findings indicate that the incongruence between motivational motor action and emotion promotes DT.

Participants with approach arm motor action (i.e., arm flexion) exhibited better DT performance in the negative emotion than in the positive emotion. Results demonstrated higher fluency, originality, and flexibility for participants with negative emotion than those with positive emotion during arm flexion (see Figs. 2, 3, and 4). As approach motivation is accompanied with positive stimuli while avoidance motivation with negative stimuli, it is reasonable to identify approach motor action as incongruent with negative emotion, or avoidance motor action incongruent with positive emotion (Yeh et al., 2016). Previous work has found that the incongruence effect can facilitate creative thinking. For example, individuals preferring rational thinking showed better DT when asked to use an intuitive thinking style (i.e., incongruence condition) than use a rational thinking style (i.e., congruency condition) (Dane, Baer, Pratt, & Oldham, 2011). In addition, the incongruence between pre-existing mood and induced emotion facilitates creative performance (Forgeard, 2011). Incongruence places oneself in a novel context, which is beneficial for novel idea generation (Dane et al., 2011). Specifically, people tend to consider the environment as novel and unusual in incongruent context, which promotes the combination of unrelated ideas.

Moreover, avoidance-motivated participants with positive emotion came up with more ideas than those with negative emotions (see Fig. 2). Except for the incongruence effect explanation, researchers have demonstrated that the DT of avoidance-motivated individuals can be enhanced when the hedonic tone of affective reactions was moderated by optimism. Positive emotions evoked by optimism can mitigate negative emotion induced by avoidance motivation, which can broaden individuals' attention scope (Icekson et al., 2014). Instead of optimism's moderation, the present study induced explicit emotion by asking participants to watch videos. We found explicit positive emotion enhanced avoidance-motivated individuals' DT in terms of fluency. Therefore, the induced positive emotion may attenuate the possible negative effect of arm extension on DT. However, the attenuating effect only works on fluency but not on flexibility and originality in the current study. According to the serial-order effect of DT-the creative quality of ideas tends to increase over time, earlier ideas generated by participants are not novel (Beaty & Silvia, 2012). It is possible that the attenuating effect of positive emotion on avoid motor action works only at the earlier time during creative thinking process.

Consistent with previous studies, the present study found more ideas were generated during arm flexion than that during arm extension (Friedman & Förster, 2002; Hao et al., 2014). From the perspective of evolutionary psychology, individuals flex their arms to approach tempting stimuli and extend their arms to avoid aversive ones (Cacioppo et al., 1993). Thus, when flexing arms, individuals may perceive the environment as safe. Therefore, they prefer to use the heuristic process strategies to solve problems. Alternatively, with arm extension, individuals may perceive the environment as dangerous. Thus, they prefer to use systematic process strategies to avoid threats. Heuristic processing strategies promote DT, whereas systematic processing strategies undermine DT (Friedman & Förster, 2002).

Of note, positive and negative emotions' influence on DT showed no difference. In this study, happiness was induced as a positive mood and fear as a negative state. Both are similar in activating but different in valence (De Dreu et al., 2008). Activating moods (e.g. fear, happiness) led to higher fluency and originality than deactivating moods (e.g. sadness, depression) (De Dreu et al., 2008). Moreover, prevention-focused mood states that activated the individuals (unfulfilled prevention goals, fear) would lead to similar levels of DT as promotion states (i.e. happiness) (Baas et al., 2011). As happiness and fear in the present study were both activating emotions, they may exert similar effects on DT. Moreover, effort of performing arm motor actions and enjoyment of tasks showed no difference between arm flexion and extension in this study. These findings excluded the possible effects of these two factors on DT.

The study had some limitations. First, we manipulated arm flexion and extension as motivational motor actions, but did not check the association of them. As previous studies have shown the strong association between arm flexion/extension and approach/avoidance, it is rational to conceive it as a solid way to induce approach and avoidance motivation. Second, our findings showed the interaction effect between emotion and motivational motor action on DT. However, the emotion valence and arousal varied in the same direction for positive emotion after induction. Therefore, we must admit that it is impossible to clarify the differential impact of valence and arousal on the interaction between emotion and motivational motor action. The interaction of motivational motor action, valence, and arousal on DT should be further analyzed in future studies. Third, although we checked the valence and arousal of the induced emotion, specific induction of happiness and fear was not checked. Future studies should check the induction of specific emotional state like fear or happiness as well.

Declarations of interest

None.

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情绪智力的负面效应及机制*

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摘 要 情绪智力是知觉、使用、理解与管理情绪的一组能力。既有研究常将情绪智力与其亲社会性联系起来,却忽视了它可能存在的负面效应。工作场所中情绪智力的负面效应体现为对内有损身心健康和工作绩效, 对外导致情绪操控和消极行为,其内在机制可结合自我损耗效应与情绪智力策略模型进行探讨。未来研究 应进一步探讨情绪智力负面效应的内在心理机制和特定情境机制,以及开展群体层次的情绪智力负面效应 研究。

关键词 情绪智力;负面效应;自我损耗;情绪智力策略模型 分类号 B848;B849:C93

1 前言

自 Goleman (1995)的畅销书《情绪智力》出版以来,情绪智力(emotional intelligence, EI)备受 学界和业界的青睐,认为它是有效应对和处置各 种难题的核心要素或品质特征。《哈佛商业评论》 甚至开设了情绪智力专栏,刊载了数十篇情绪智 力专题研究论文。在业界,也涌现出大量有关情 绪智力的培训服务项目,据估计几乎 75%的世界 500 强公司都使用过情绪智力培训产品(Bradberry, Greaves, & Lencioni, 2009)。可见,在公众视野中, 情绪智力即使不是决定成功的唯一品质,也是最 主要的核心素质。

在学界,情绪智力研究常与亲社会性联系在 一起。首先,情绪智力因其良好的情绪调节能力, 有助于个体保持良好的情绪状态和心理健康 (Burrus et al., 2012; Hansen, Lloyd, & Stough, 2009);其次,情绪智力有利于移情、合作行为等, 从而促成良好的人际关系(Reis et al., 2007);再次, 情绪智力有助于个体应对职场压力,获得较高的 工作满意度和工作绩效(Ouyang, Sang, Li, & Peng, 2015; Lam & Kirby, 2002; Joseph, Newman, & O'Boyle, 2015)。此外,从团队绩效来看,情绪智 力与人际互动的质量相关,高情绪智力的团队, 其凝聚力越高、合作行为越多,进而有助于团队 绩效的提高(Jordan & Troth, 2004; Farh, Seo, & Tesluk, 2012); 等等。

既有研究表明,情绪智力的确与积极结果高 度相关,比如良好的关系、优异的工作绩效等 (Mayer, Roberts, & Barsade, 2008)。但是, 对于这 些指标,情绪智力到底发挥了多大的作用,它是 否真的能有效地预测成功?一些学者敏感地提出 了质疑。Salovey 和 Mayer (1990)在提出情绪智力 概念时便指出"当个体的情绪技能被反社会意图 操控时,他们可能会创造操控性场景或在互动过 程中损害他人利益" (P.198)。Salovey 和 Mayer 虽 较早地指出情绪智力被消极运用的可能性,但他 们并未进一步研究"谁会消极运用情绪智力"。 Bass 和 Steidlmeier (1999)关于真、伪变革性领导 的研究对此做出了探讨。真正的变革型领导使用 情绪智力激励和鼓舞追随者,真正关心如何提升 组织效能;而伪变革型领导以自我为中心,为实 现自我目标而运用情绪智力,有时甚至以牺牲他

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人利益为代价。

随着研究的深入,少数学者在 Salovey 和 Mayer质疑的基础上讨论了"为什么情绪智力可能 会存在负面效应"(Härtel & Panipucci, 2007; Jordan, Ashton-James, & Ashkanasy, 2006; Kilduff, Chiaburu, & Menges, 2010)。他们认为,高情绪智 力意味着拥有更多的情绪识别和情绪调控能力, 进而可能会为了个人利益而伪装、塑造自己的情 绪以操控他人的感知和情绪。然而,这些观点还 停留在理论推导层面。最近, Davis 和 Nichols (2016)关于情绪智力负面效应的研究,将视角拓 展到了个体内的黑暗效应,指出在特定条件下, 情绪智力对内可能导致自我易损性(例如,高情绪 智力者可能会更多地内化他人的职业压力)。

情绪智力的负面效应虽引起了一些学者的关注,但相关研究仍非常不充分。因此,本研究呼应 Kilduff 等(2010)"将情绪智力与可贵的道德品质 相剥离"的号召,聚焦于工作场所中情绪智力的 负面效应,深入探讨其背后的心理机制和理论基 础,并在分析该领域现有研究不足的基础上,针 对性地提出了情绪智力消极面的未来研究方向。

2 情绪智力的概念与结构

2.1 情绪智力的概念

现有的文献中,关于情绪智力的界定主要存 在两种视角。其一,能力型情绪智力(ability emotional intelligence, AEI)流派,认为情绪智力 是与情绪活动有关的能力;其二,特质型情绪智 力(trait emotional intelligence, TEI)流派,有时也 被称为混合情绪智力(mixed emotional intelligence) 流派,该流派将情绪智力视为个性和能力的结合 体(Walter, Cole, & Humphrey, 2011)。

特质型情绪智力的概念把一些与"情绪"无关的内容(如品德和个性等)都包含在内,一直都受到学术界对其概念界定过于宽泛和松散的批判(Wong & Law, 2002)。情绪智力的能力流派将情绪智力与人格特质进行了严格区分,使用的测量工具具备更优的心理测量学特性(Daus & Ashkanasy, 2005)。故本研究倾向于认同能力型情绪智力的界定,将情绪智力视为与情绪活动相关的一组技能,涉及"准确地感知、评价和表达情绪的能力;接近或产生促进思维的情绪能力;理解情绪和情绪知识的能力"(Mayer & Salovey, 1997)。

2.2 情绪智力的结构与测量

Salovey 和 Mayer (1990)将情绪智力划分为四 个不同的维度: (1)自我情绪评定(self emotional appraisal, SEA),涉及个体理解自己的深层情绪并 能够自然地表达这些情绪的能力; (2)他人情绪评 定(others' emotional appraisal, OEA), 指人们感知 和理解周围人情绪的能力。(3)情绪调节(regulation of emotion, ROE),即调节情绪的能力,这使人们 能够更快地从高兴或痛苦中恢复至正常状态。(4) 情绪使用(use of emotion, UOE),即使用情绪的能 力,该能力有助于指导个体进行建设性活动,以 及完善他们的表现。

Wong 和 Law (2002)开发的情绪智力自陈量 表正是基于 Salovey 和 Mayer 的情绪智力结构模 型,量表维度与上述结构一致,各维度均包含 4 个题项,共16个题项。除了自陈量表,还可采用 任务测验的方式测量能力型情绪智力,其中 MSCEIT (Mayer, Salovey, Caruso, & Sitarenios, 2003)是认可度较高的任务测验。测验的计分标准 有两种——群体标准(按照大样本的反应频数为 标准记分)和专家标准(以专家的反应频数为标准 计分)。依据测验得分与标准分的符合程度来评估 情绪智力。

3 情绪智力的负面效应

情绪智力并非总是积极的,理由在于:第一, 情绪智力是一种与情绪相关的能力,它与其他任 何技能一样,既能服务于善良的意愿,也能被非 善良甚至邪恶的目的所利用(Grant, 2014);第二, 人是复杂体,不一样的个体有着不同的特质、动 机和价值观,以及他们与组织环境的互动也不尽 相同(如高情绪智力者更擅长审时度势),当这些 因素与情绪智力共同作用时,情绪智力的效应是 大相径庭的。

本研究将依据情绪智力发挥作用的场合(独 处与社会性接触场合)(张辉华,2014),基于"个体 内/人际间"维度对情绪智力的负面效应研究进行 归纳和总结(见表 1)。

3.1 个体内的负面效应

3.1.1 情绪智力与身心健康

一些研究发现了高情绪智力者常常有更高的 压力反应。Bechtoldt和 Schneider (2016)研究了情 绪智力和压力反应的关系以及睾酮的调节作用, TEI

TEIQue

表Ⅰ 情绪智刀的负面效应							
EI 流派	测量工具1	结果变量	调节变量	研究者			
AEI	MSCEIT	压力(皮质醇水平)	睾酮水平	Bechtoldt & Schneider, 2016			
TEI	EQ-I; TEIQue	焦虑、愤怒、精力的削弱		Petrides & Furnham, 2003			
AEI	SSEIT	创伤后成长		Li et al., 2015			
AEI	MEIS; SSEIT	沮丧、自杀念头、绝望	日常麻烦	Ciarrochi et al., 2002			
TEI;AEI	TEIQue; MSCEIT	心理适应、沮丧	家庭功能失调、经济损失	Davis & Humphrey, 2012; Davis & Humphrey, 2014			
TEI	TEIQue	使他人情绪变糟的倾向	宜人性	Austin, et al., 2014			
AEI	MSCEIT	夫妻关系质量		Brackett et al., 2005			
AEI	MSCEIT	偏差行为	马基雅维利主义	Côté et al., 2011			
TEI	MEIA	作假行为	作假机会、 认知能力	Tett et al., 2012			
AEI	SSI	情绪操控	黑暗人格	Nagler et al., 2014			
AEI	WEIT	作弊行为		Gentina, Tang, & Dancoine, 2018			

注: 该表在 Davis 和 Nichols (2016)等的研究的基础上整理所得。AEI 指能力情绪智力; TEI 指特质情绪智力。MSCEIT、MEIS 为能力情绪智力的任务式测量法; SSEIT、SSI、WEIT 为能力情绪智力问卷式测量工具; EQI、TEIQue、MEIA 为特质情绪智 力问卷式测量工具。

选用皮质醇作为压力的生理指标,结果发现,在 社会要求情境下,高情绪智力者往往有更高的压 力水平,睾酮得分越高,这种关系越强烈。另外, Bechtoldt和Schneider (2016)还指出高情绪智力者 从这种高皮质醇水平中的恢复速度更慢。Petrides 和 Furnham (2003)的实验研究发现, 高情绪智力 者能更快地感知到情绪, 然而, 在观看了沮丧的 电影后,高情绪智力者也报告了更高的焦虑、愤 怒水平和更低的精力水平。

原发性精神病态、

继发性精神病态²

还有一些研究关注了情绪智力与心理疾病间 的关系。Li 等(2015)以护理专业的学生为被试,发 现相较于中等水平情绪智力的学生, 那些拥有过 高或者过低情绪智力的学生在面临童年创伤后的

成长水平较低。Ciarrochi等(2002)发现,当个体遇 到更多日常的麻烦事(daily hassles)时,高情绪智 力常常导致高度的沮丧、自杀念头和绝望。类似 地, Davis 和 Humphrey (2012, 2014)发现, 在家庭 功能失调或者面临经济损失时,高情绪智力者存 在更高的心理适应问题和更高的沮丧水平。

Sample, 2017

3.1.2 情绪智力与绩效

当工作活动不需要情绪智力时,情绪智力可 能存在隐性代价(Grant, 2014)。例如, Joseph 和 Newman (2010)的一项元分析中,综合分析了几 百项研究中情绪智力和工作绩效的关系,这些研 究中的样本涉及 191 个不同岗位的上千名员工。 结果表明,情绪智力与工作绩效间并没有一致性 的关系,即当工作需要倾注大量的情绪时,情绪 智力越高, 绩效越好; 反之, 对于不需要倾注过 多情绪的工作,高情绪智力可能是缺点而非优 点。Grant (2014)对情绪智力之于工作绩效可能的 负面效应做出了解释,即在无需过多情绪活动的 工作中,高情绪智力的员工在本应专心完成任务 的时候,却把注意力放在了情绪上。比如,在分析 数据或修理汽车的工作中,察言观色会分散注意 力。Khanna 和 Mishra (2017)也提出了类似的观点, 认为在对情绪需求较少的工作中(例如机械、科学 研究和宇航等),情绪智力并不利于工作绩效。

¹ 在整理情绪智力负面效应相关研究的过程中发现情绪智 力的概念流派、测量工具有所不同。这容易产生疑问:情 绪智力的负面效应是由于情绪智力概念、或是测量工具的 差异带来的吗?从现有的研究来看,我们可以排除情绪智 力负面效应单纯源于概念流派、测量工具的混用。然而,概 念和测量工具的不一致为情绪智力负面效应带来了多大的 误差,还需更多的研究来检验。

²精神病态(psychopathy)被定义为一种以反社会心理和行为 为特征的人格特质。原发性精神病态(primary psychopathy) 的特点是冷酷无情、操纵、自私和虚伪;继发性精神病态 (secondary psychopathy)的特点是参与冲动的行为和自我挫 败的生活方式。

3.2 人际间的负面效应

3.2.1 情绪智力与人际操纵

情绪智力可能导致人际间的情绪操纵与欺骗。Brackett等(2005)研究了情绪智力与夫妻关系 质量的关系,研究发现,相比于情绪智力都不是 很高的夫妻,夫妻二人都有高情绪智力时经常在 夫妻关系质量上得分更低。该研究同时指出,虽 然夫妻两人情绪智力都低将导致糟糕的夫妻关系 质量,但当一人情绪智力高或两人情绪智力都高 时,这并不会显著改善夫妻关系质量。情绪操控 也发生在非夫妻关系中,Austin等(2014)认为,虽 然情绪智力与使他人情绪变糟的倾向负相关,但 是宜人性起到边界调节的作用,即当个体的宜人 性较低时,高情绪智力者更有可能使他人情绪变 糟。类似地,Nagler等(2014)指出具有黑暗人格的 个体更善于运用情绪技能操控他人。

3.2.2 情绪智力与人际间消极行为

有研究指出情绪智力导致了更多的人际间消 极行为。Côté 等(2011)的研究指出,个性特征激发 了相关的目标,情绪能力帮助个体实现目标。他 们通过两个研究探讨了情绪智力与道德同一性的 交互作用对亲社会行为的作用,以及情绪智力与 马基雅维利主义的交互作用对人际偏差行为的影 响。结果发现,高情绪智力者既可能带来更多的 亲社会行为,也可能产生更多的人际偏差行为, 究竟产生何种效应取决于个体特质诱发了何种个 人目标,即,具有道德同一性的高情绪智力者的 亲社会行为更多, 而手段最险恶的员工正是高情 绪智力的马基雅维利主义者。Côté 等(2011)进一 步指出,情绪智力本身既不是正面的,也不是负 面的,但却可以通过对情绪的有效监管帮助个体 目标的实现,这些目标可能是亲社会性的,也可 能是反社会性的。此外, Tett 等(2012)的研究发现 了情绪智力与作假行为之间的关系, 当个体有机 会作假时,具有高认知能力与高情绪智力的个体 会表现出更多的作假行为。

4 情绪智力负面效应的机制探析

虽然上述研究一定程度上证实了情绪智力的 负面效应,然而鲜少有研究对其内部机制进行分 析与解读。本研究对情绪智力负面效应的机制探 析同样采用"个体内/人际间"维度。基于自我损耗 理论和资源保存理论探讨情绪智力对个体自身的 负面效应,并结合情绪智力策略模型探讨情绪智 力在人际间的负面效应。

4.1 自我损耗效应

一般而言,在处理情绪事件时,高情绪智力 者的自我损耗程度应低于低情绪智力者。然而, 一些研究将高情绪智力与高内在损耗联系起来。 例如, Davis 和 Humphrey (2012, 2014)指出,在家 庭功能失调或者面临经济损失时,高情绪智力者 存在更大的心理适应问题和更高的沮丧水平。为 何高情绪智力反而会带来更高的内在损耗?

自我损耗理论(Ego Depletion Theory)对上述 现象进行了阐释。该理论认为,调控情绪和思维 都会消耗心理能量,而所有需要心理能量的活动 使用的是同一种资源——自我控制资源,之前的 意志活动造成的自我控制资源的损耗将导致随后 意志活动控制水平的下降(Baumeister, Bratslavsky, & Tice, 1998),此即"自我损耗"现象。控制环境 (controlling the environment)、控制自我(controlling the self)、做出抉择(making choices)和发起行动 (initating action)等都属于意志活动(Baumeister et al., 1998)。情绪的评估、调节和使用是一种有意 的控制行为,亦会损耗自我控制资源,进而影响 随后的意志行为。

自我损耗理论虽对损耗效应以及其中所涉及 资源进行了清晰的描述,然而该理论无法解释 "高情绪智力者为何消耗更多的自我控制资源"。 故本文采用资源保存理论(Conservation of Resources Theory)的"资源投入-产出不平衡"角度 来解释情绪智力自我损耗效应的内部机理。

高情绪智力者面临着更高的工作要求(非正 式工作规范要求),这种要求可能源于他人和自身 的高期待。例如,高情绪智力者很可能会被组织 中那些与其有关联的个体的情绪所影响——帮助 他们处理工作中的负面情绪(Toegel, Anand, & Kildiff, 2007)。高情绪智力者可能需要经常表达组 织所需的积极情绪,但这种情绪不太可能始终与 其实际感受一致,当发生冲突时,高情绪智力者 需要进行情绪调节以显示所需的积极情绪(Lin, Scott, & Matta, 2018)。Joseph 和 Newman (2010) 的元分析结果"对于不需要倾注过多情绪的工作, 高情绪智力可能是缺点"可以据此做出解释,当 正式工作规范中不涉及情绪时,低情绪智力者的 日常工作中涉及较少的情绪活动,而高情绪智力 者因其自身和他人的高期待,仍需处理大量的情 绪事件,因而会损耗其内在资源,进而影响工作 结果。

在实际的工作情境下,尤其在高压力等消极 环境下,高情绪智力者所损耗的资源可能是无法 恢复的。高情绪智力的个体更为深刻地感知负面 事件,并试图调用更多的资源来处理所遇到的困 境。当所遇的困境得到顺利解决,高情绪智力者 所耗损的资源可得到一定程度的恢复,但当所遇 到的困境难以解决并且长期存在时,高情绪智力 者则将面临更严重的资源损耗和更艰难的资源恢 复。这在一定程度上可以解释"高情绪智力者与心 理疾病相关联"的现象(Ciarrochi et al., 2002; Davis & Humphrey, 2012, 2014)。

4.2 情绪智力策略模型

Kilduff 等(2010)探讨了组织领域中,人们如 何通过使用情绪策略来控制互动结果,从而在竞 争中获得成功。基于能力型情绪智力的相关观点 (如: Salovey & Mayer, 1990; Mayer & Salovey, 1997), Kilduff 等(2010)提出,在具有竞争压力的 情境下,情绪智力赋予个体四种情绪能力,这些 能力的策略性使用为个体谋取自身利益、获取竞 争优势提供可能。图 1 展示了情绪智力能力与自 利策略之间的关系,同时也示明了这些能力本身 的层级关系。



图 1 情绪智力策略模型 注:该图依据 Kilduff 等(2010)的研究整理而得,实线箭头 表示采用自利战术所需的情绪智力能力;虚线箭头表示更 高层级的情绪智力能力包含更基本的情绪智力能力。这四 种自利策略的排列顺序反映了高情绪智力者对他人操控的

升级。

如图1所示,第1种自利策略(关注战略上的 重要目标)需要有感知自我和他人情绪的能力,以 及运用情绪智力促进思考的能力。简单地说,高 情绪智力者会有选择地利用这些能力来关注有利 于或阻碍其晋升的人,忽视无关人员的情绪。例如, 就下属视角而言,在每个组织中,负责控制绩效评 估和加薪的主管的情绪很可能被下属仔细研究。

第2种自利策略(为了个人利益而伪装或表达 情绪)运用了情绪智力中管理自我和他人情绪的 能力。Kilduff等(2010)认为,高情绪智力者可以故 意塑造自己的情绪,从而制造出对自己有利的印 象,或是为了实现目标,表现出适宜、却有违内心 感受的情绪。例如,精明的扑克玩家可以用中性 的表情来掩盖麻烦,或者在面对平庸的牌时高兴 地微笑。

就第3种自利策略(为了个人利益激发和塑造 他人情绪)而言,人们在并不完全明白自己的感受 以及为何有这种感受时,很容易受到其他人的可 信解释的影响(Brodt & Zimbardo, 1981),高情绪 智力者则善于通过错误归因来改变事件的意义, 或是为了自身利益以微妙的方式分析不确定的情 况。因此,高情绪智力者常常帮助同事解释不明 确的感觉,这种解释充满了利己主义色彩。

就第 4 种自利策略(情绪信息的战略控制)而 言,高情绪智力者通过控制信息流动来影响他人 声誉,或是通过选择性的交流和资源分配来唤起 他人不同的情绪反应,以影响他们的决策和行 为。例如,高情绪智力的主管可能会过度奖励下 属,以利用下属在面对意外或不义之财时的负罪 感和感激之情,促使下属接受不吸引人的、不道 德的,甚至非法的任务。

Khanna 和 Mishra (2017)在 Kilduff 等(2010)的 研究基础上进一步探讨了人际间情绪智力的负面 效应。第一,人际关系方面情绪智力的负面效应, 高情绪智力者通过控制自己的情绪来获得他人的 信任,再通过他人的信任控制信息流动,进而来 提升自己的利益。第二,领导层面情绪智力的负面 效应,高情绪智力的主管可以使用情绪策略操控 下属,从而获得理想的结果,而这可能对下属产 生不良影响。Grant (2014)亦指出高情绪智力的领导 可能出于自利的动机而操控他人,对于他们而言, 情绪管理能力仅仅是实现目标的工具,而目标则 既可以是善的,也可以是恶的。Bausseron (2018) 则通过内容分析对 Kilduff 等(2010)的情绪智力的 策略模型进行检验,发现自我关注(self-focused) 的领导更容易策略性地运用情绪能力。

5 总结与展望

尽管情绪智力的负面效应已引起一些学者的 关注(Kilduff et al., 2010; Grant, 2014; 李一茗, 邹 泓,黎坚, 危胜男, 2016),现有研究对此也做出 了一些初步的尝试,但这些研究成果大多缺乏深 入的探讨或停留于理论层面。总的来看,情绪智 力负面效应的内在机制目前仍是一个"黑箱",对 这一问题的探索无疑是一项既有挑战性又非常有 趣的任务。因此,结合上文对已有文献的梳理和 相关理论的阐述,我们提出如图 2 所示的情绪智 力负面效应研究设想整合模型。该模型主要聚焦 于以下几个方面的问题:

第一,情绪智力负面效应的内在心理机制。 已有研究常常将高情绪智力和心理疾病联系起来 (Davis & Nichols, 2016; Furnham & Rosen, 2016), 然而,这些研究大多只是做简单的相关分析,并 未对其原理进行深入探究。根据资源保存理论, 高情绪智力者因其较高的情绪能力,将更多地关 注组织中的情绪事件;同时,高情绪智力者会接 收到来自他人及其自身的高期待和高要求,他们 在处理情绪事件时,其处理态度、方式,以及资源 的调用都与低情绪智力者有所不同,可能会产生 "能力越大,责任越大"的现象,进而带来更多的 自我损耗。未来的研究可将与资源消耗相关的变 量(如:自我损耗、情绪耗竭和工作疲劳等)作为解 释情绪智力与个体内在消极结果间的中介机制。

人际视角的情绪智力研究虽已尝试将情绪智

力与自利策略结合起来,但这些研究还停留在理 论层面(Kilduff et al., 2010; Grant, 2014; Khanna & Mishra, 2017),而在现今高度竞争的组织环境下, 那些善于辨别组织内部情绪暗流并对其采取行动 的员工,更可能取得成功。具体而言,高情绪智力 的员工善于利用信息的"生动效应"来达到自己的 目的,比如用动人心弦的语言描述事件,运用具 体的例子和吸引人的比喻,而非仅仅依靠统计数 据或理性的证据(Kilduff et al., 2010)。高情绪智力 者的一个常用策略便是印象管理。例如,高情绪 智力的员工可以将其自利行为通过印象管理塑造 成无私的行为(Kilduff et al., 2010)。未来的研究中, 我们需要进一步探讨非亲社会动机、非自主动机 (如印象管理动机和自我提升动机等)在情绪智力 和负面结果间的中介作用。

另外,未来的研究还可以就"如何解读他人 的策略性行为"来挖掘策略化使用情绪智力对观 察者的消极影响。高情绪智力者的策略性行为带 来何种结果很大程度上取决于观察者对此种行为 的归因和评价。在情绪智力研究中,Dasborough 和 Ashkanasy (2002)的情绪和意向性归因模型提 出了追随者关于其领导者意图(真诚或操纵)的归 因,导致他们将其领导者归类为真正的或伪变革 的领导者。观察者对行为者意图的归因又将影响 其后续的行为表现。结合社会学习理论(Social Learning Theory),对行为者的消极归因与行为者 的积极行为结果(如伪变革型领导为满足个人利 益而采取的策略行为获得了积极结果)容易引起



注:¹代表该变量主要在个体内层次产生影响;²代表该变量主要在人际间层次产生影响;因文献资料的不充分,模型中未呈现群体层面情绪智力的负面效应。

观察者的不公平感,甚至产生对消极行为的模仿 效应。未来的研究还需关注并研究如何避免"消极 归因→消极行为模仿"这样一种恶性循环。

第二,情绪智力负面效应发生的情境条件。 在现有的研究中,有些学者将情绪智力与身心健 康联系起来(Mayer, Roberts, & Barsade, 2008),也有 学者将情绪智力与心理疾病联系起来(Davis & Nichols, 2016; Furnham & Rosen, 2016),这表明情绪 智力产生何种作用取决于行为者所处的特定情境。

未来的研究可以从个体所需面对的内外部压 力环境来探讨高情绪智力者内在损耗所需的特定 条件。这种压力既可以是客观压力环境,也可以 是心理上的压力环境。例如,领导者便是一个重 要的客观压力源,高情绪智力者会尤为关注负责 控制绩效评估和加薪的领导(Kilduff et al., 2010), 他们会对领导情绪的微妙暗示感兴趣,包括领导 的声音语调、面部表情和其他非语言手势,这些 信息暗含了领导的观点、偏好和潜在行为倾向 (Sanchez-Burks & Huy, 2009)。

个体特性可能为高情绪智力者带来心理上的 压力环境。例如, Snyder (1974)提出的自我监控概 念,他认为高自我监控者重视外界因素,思考如 何在特定情境中做出适宜行为,依靠外界信息反 馈调整自己的行为;而低自我监控者则重视自身 因素,依据自身特点和内部状态等进行行为调 节。实行自我监控的员工就如同"照镜子"——修 正自我外显行为并注意观察他人的行为反馈。可 推知,当高情绪智力者的自我监控水平较高时, 极易产生较高的心理压力与内在损耗。

基于人际视角的情绪智力研究虽已开始将情 绪智力与个体特征相结合,认为两者共同作用时, 既有可能产生积极的效果,也有可能带来负面效 果。如 Côté 等(2011)的研究发现,情绪智力与道 德同一性的交互作用促进了亲社会行为;而情绪 智力与马基雅维利主义的交互作用却与人际偏差 行为显著相关。但此类研究还很不充分。未来的 研究可以继续深入挖掘"谁会策略化使用情绪智 力"以及"何时会策略化使用情绪智力"。竞争性 (competitiveness)作为一种个体特征,它可以引发 公民努力(citizenship efforts)并提高绩效,也会引 发蓄意破坏等不道德行为 (Charness, Masclet, & Villeval, 2013)。理论上,当竞争性很高时,高情绪 智力者更容易运用其情绪智力进行策略行为以满 足其个人利益。一项情绪智力研究一定程度上佐 证了这一设想,该研究运用囚徒困境来研究不同 情绪智力者如何决策,研究发现高情绪智力者在 面临两难选择时,更可能为实现个人利益最大化 而选择竞争(Fernández-Berrocal, Extremera, Lopes, & Ruiz-Arande, 2014)。此外,组织环境的竞争程 度是否与策略化行为同样存在关联?这有待遇于 未来更多的研究进行探讨和检验。

第三,群体层面情绪智力的负面效应。综观 情绪智力负面效应的实证研究和理论探讨,可发 现以往研究几乎不曾涉及群体层面情绪智力的负 面效应。大多群体层面情绪智力研究对其影响效 果持积极观点,认为高情绪智力的群体通常冲突 少、凝聚力高以及合作行为多,进而产生更高的 群体绩效(Dasborough & Ashkanasy, 2002; Wolff, 2005)。然而,在组织的日常实践中,"融洽"却不作 为的群体并不少见。显然,已有研究不足以解释 群体情绪智力可能带来的负面效应。未来群体层 面情绪智力影响效果的研究需区分情绪智力对不 同类型绩效(如任务绩效和创新绩效)的影响。正如 Chamorro-Premuzic 和 Yearsley (2017)指出的, 情 绪智力可能导致较低的创造力和创新潜力。此外, 简单的线性关系也许不能充分解释情绪智力与绩 效间的关系,未来的研究应尝试探讨两者间存在 更为复杂关系的可能性。

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Negative effects and mechanisms of emotional intelligence

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Abstract: Emotional intelligence (EI) comprises of a set of abilities related to detecting, using, understanding and managing emotion. Researches and discussions of EI have disproportionately focused on pro-social outcomes but have neglected the possibility that EI might have a dark side. EI in the workplace was negatively related to physical and mental health and job performance at the within-individual level, and led to emotional manipulation and negative behavior at the between-individual level. The internal mechanism of negative effects of EI can be analyzed by the ego-depletion effect and emotional intelligence strategy model. Furthermore, psychological mechanism, situational moderators and negative effect of EI at the team level provide us with important clues to guide future research.

Key words: emotional intelligence; negative effects; ego-depletion; strategic use of emotional intelligence

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建议采纳的认知机制*

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摘 要 决策者的认知特点,以及决策过程中建议者、任务特征、环境因素等都会影响决策者的认知加工,并 最终影响建议采纳。目前建议采纳过程中的认知研究主要集中于决策者方面,本文通过总结以往研究,从决策 者的认知风格、社会认知复杂性、认知策略以及情绪对认知的影响等四个方面,系统阐述了认知对建议采纳 的影响。同时,结合态度改变理论、解释水平理论、具身认知理论以及认知失调理论等进一步讨论了建议采 纳的认知发生机制,并在此基础上初步构建了建议采纳认知机制模型。未来研究可进一步探讨决策者的认知 灵活性、认知闭合需要等对建议采纳的影响,以及建议提出的认知机制,以丰富建议采纳领域研究。 关键词 建议采纳;认知机制;态度改变理论;解释水平理论;具身认知理论;认知失调理论 分类号 B849:C91

1 引言

建议提出和建议采纳渗透在我们生活的每个 角落。不确定的决策困境遍布于生活之中、小到 午餐吃什么、约会穿什么、大到志愿选择、健康 问题等, 仅凭个人力量很难做出尽善尽美的决策, 因此,别人的建议是帮助我们提高决策质量的重 要资源(Larrick, Mannes, & Soll, 2012), 合理使用 他人建议也是我们人生必备的一项技能。虽然专 业性的建议对我们提高决策质量至关重要,但是 在现实生活中,我们常常为了维护自己的权威或 证明自己的正确性而忽略他人的建议(Brooks, Gino, & Schweitzer, 2015), 从而产生建议折扣现 象。这也引起了学者们的兴趣并由此展开了一系 列的研究(Schultze, Rakotoarisoa, & Schulzhardt, 2015; Comes & Schwabe, 2016), 目前建议采纳 研究大多采用"决策者-建议者系统"范式(Judge-Advisor System, JAS; Sniezek & Buckley, 1995), 该范式包括决策者、决策任务和建议者三个主要 元素。在面对不确定问题时,决策者会收到一条

通信作者:田晓明, E-mail: tianxm@mail.usts.edu.cn 段锦云, E-mail: mgjyduan@hotmail.com 或多条建议,建议可以来自于真实存在的建议者, 也可以是根据实验目的事先设定好建议值,最后 决策者对建议进行认知加工,决定是否采纳建议, 并做出最终决策。JAS 范式并不是一成不变,可 以按照初始决策-参考建议-最终决策的模式 (independent-then-revise advice sequence)来开展 研究,也可以直接呈现建议,再让决策者做出决 策(Rader, Soll, & Larrick, 2015)。

建议采纳研究的核心问题是什么时候建议更 容易被接受(段锦云,周冉,陆文娟,李晶,朱宜 超, 2013), 以往对建议折扣的探究大都关注决策 过程中的情境因素,例如任务难度(Gino & Moore, 2007; Schrah, Dalal, & Sniezek, 2006)、建议特征 (Tzioti, Wierenga, & van Osselaer, 2014)等, 近年 来,一些研究开始聚焦于个体差异对建议采纳的 影响 (Kausel, Culbertson, Leiva, Slaughter, & Jackson, 2015; 段锦云, 古晓花, 孙露莹, 2016), 而认知因素就是重要的影响源之一。当面对众多 建议时,决策者是充耳不闻还是从谏如流,不仅 仅是决策者与建议者人际互动的结果, 也是其对 信息进行认知加工的结果。从认知角度来说,决 策者和建议者的认知特征都会影响到决策者对建 议的评估,从而影响建议采纳。那么认知究竟如 何影响建议采纳?目前还没有相关文献对此进行 全面论述,本文尝试围绕 JAS 系统,对建议采纳

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中的认知研究进行梳理与整合,基于相关决策理 论,从决策者自身认知特征,如认知风格,认知 复杂性,认知策略以及情绪对认知的影响等方面 来归纳建议采纳的认知发生机制,寻找促进或阻 碍建议采纳行为的认知因素并加以整合,并构建 了建议采纳的认知机制模型。最后文章对未来研 究方向提出了具体建议,旨在为建议采纳及相关 决策研究提供参考和借鉴。

2 建议采纳的认知影响因素

结合以往研究,本节将主要从认知风格、社 会认知复杂性、认知策略以及情绪对认知的影响 四个方面着重分析和阐述决策者的认知特点对建 议采纳的影响。

2.1 认知风格

认知风格是影响个体进行判断和行为决策的 重要因素(Armstrong, Cools, & Sadler-Smith, 2012), 它反应的是个体思考和解决问题的偏好。在相关 研究中, Witkin (1964)的研究将认知风格按依存特 征划分为场独立型和场依存型两种类型。

大量研究表明,认知风格会在不同情境下影 响决策行为及建议采纳。有研究发现,在群体情 境中,认知风格在很大程度上影响了个体对他人 建议的反应,场独立个体倾向于坚持自己的初始 决策,不愿接受他人建议;而场依存个体则会仔 细地考虑他人观点。闫婷婷、杜秀芳和李假(2014) 在前人研究基础上进一步探究,发现场依存型比 场独立型的决策者更愿意采纳建议,这是因为场 独立型的决策者根据内部经验和逻辑分析来加工 信息(Wang, Hao, Maguire, & Hu, 2016),在信息加 工过程中投入更多的注意资源和认知努力,且基 本不受决策问题表述方式的影响(韩玉昌,张健, 杨文兵, 2014),因此能更独立自主的做出决策; 而场依存型的决策者更加被动,并且缺乏主见, 做决策时更多依赖参照信息。

也有学者从信息加工方式的角度将认知风格 分为系统1和系统2,系统1又称直觉系统(intuitive system),其特征为决策速度快、自动化的、内隐 的、欠考虑的;系统2 又称分析系统(analytical system),其特征为决策速度慢、受控制的、有意 识的、基于规则的、深思熟虑的(Stanovich & West, 2000; Kahneman, 2003; Dewberry, Juanchich, & Narendran, 2013)。Tzioti 等人(2014)在其研究中根 据建议提出时所采用的信息加工方式不同,将建 议分为直觉型建议和分析型建议,结果发现比起 直觉型建议(根据我的经验),决策者更偏好分析 型建议(市场调查结果表明),但是这种关系受到 决策者和建议者资历的影响,当建议者资质较低 时,决策者不受其直觉型建议的影响,而其分析 型建议则会使决策者在一定程度上改变观点;当 建议来自资质较高的建议者时,无论是直觉型建 议还是分析型建议,都能使决策者改变其观点。 也就是说,对直觉型建议的利用依赖于建议者的 资质,而对分析型建议的采纳则不受资质影响。

建议者认知加工方式的不同会导致提出的建 议类型不同,分析型的建议更易受到决策者的青 睐,而直觉型建议只有当建议者资质高(比如是专 家)时才会被采纳,这也进一步说明了认知加工方 式(或风格)不仅会影响决策者,也会影响到建议 者的建议提出,进而影响建议采纳。

2.2 社会认知复杂性

除了个体的认知风格外,认知复杂性也是影 响建议采纳的重要因素。社会认知复杂性(social cognitive complexity)反映的是个体的一种认知能 力,认知复杂性高的人具有高度复杂的思维能力 和认知特点,个体也具有较强的自我意识(van Seggelen-Damen, 2013)。Lohman 和 Lakin (2009) 发现社会认知复杂性与个人的推理能力是相挂钩 的,即社会认知复杂性右一定程度上反映了个人 推理能力的高低,而复杂的推理能力是优化决策 必须具备的重要能力之一(Lohman & Lakin, 2011), 高推理能力者能做出相对正确的决策,而缺乏推 理能力会降低决策质量(Moore & Tenbrunsel, 2014)。那么个体的社会认知复杂性是否影响其决 策过程中的建议采纳?

卜楠和杜秀芳(2015)在前人研究的基础上探 讨了认知复杂性对建议采纳的影响,结果发现, 低认知复杂性者更容易采纳他人意见,其中人际 信任起部分中介作用。由于低认知复杂性者推理 能力低,对问题的思考和分析不够深入,多采用 启发式的加工策略,更依赖和信任他人的建议; 而高认知复杂性者的认知方式倾向于沉思型(van Seggelen-Damen, 2013),推理能力高,对问题的 表征更复杂,思考更深入,多采用分析式加工策 略,他们更相信自己能够解决问题,对于自身原 有意见的改变显得较为保守,对建议的采纳程度 也就较低。研究也发现,决策者的认知能力会影响建议接受速度(Barham, Chavas, Fitz, & Schechter, 2018),以此类推,认知复杂性可影响决策者对建议内容的分析与判断以及对建议者的信任,进而影响建议采纳。由于目前关于认知复杂性对建议采纳的研究还较少,后续研究可以继续探讨它对建议采纳的影响机制及边界条件等。

2.3 认知策略

认知策略是个体支配认知的技能。布鲁纳首 次提出了"认知策略"一词,后来,人们把这个词 语和人的内在加工联系起来,突出了个人对自我 意志的操控。在建议采纳研究领域中,有研究者 就认知策略的影响进行了相应的研究。例如标签 效应(label effect)就是认知策略之一,就像给生活 中不同的事物贴上不同的相对应的标签一样,人 也会根据自己的内在认知,给自己贴上相应的标 签,在标签的作用下,朝着被规定的方向去发展, 或者以标签作为自己的行为标准, 使得自己的行 为与标签暗示的内容相一致(Guadagno & Burger, 2007)。因此拥有正面自我标签的人,其行为活动 也多是积极的,希望维护自己正面形象的。段锦 云、周冉和古晓花(2014)将标签效应引入到建议采 纳领域,发现正面的自我标签有利于促进建议的 采纳,并将正面自我标签、有无获益、是否公开 三者联系起来,进一步探讨了标签效应对建议采 纳的影响,研究通过两个实验发现在公开条件下, 无论是有获益希望还是无获益希望,决策者启动 正面自我标签都会促进其建议采纳、但两者内部 心理机制不同, 无获益希望的公开条件下, 决策 者采纳建议是为了维护自己的正面形象,获得大 家的认可,而有获益希望的公开条件下的决策者 启动正面自我标签后, 会有更多积极情绪的体验, 从而促进建议采纳。然而, Norton, Dunn, Carney 和 Dan (2012)却发现,对建议者启动标签后,发 现被污名化的建议者更加具有说服力, 健全的人 更容易被残疾人说服,这可能是受印象管理的影 响,人们都有在陌生人或群体面前维护自己形象 的愿望, 被贴有负面标签的建议者(如残疾人)与 决策者属于不同群体时,决策者出于获得外群体 认同的需要, 更容易被对方的信息所说服, 但是, 此研究并不能充分说明是因为给建议者贴上负面 标签而导致其更有说服力,还是仅仅给建议者贴 上不同标签后, 增加了决策者获得外群体认同和

维护自己形象的渴望,而导致其更容易被说服。 因此,未来研究可进一步探讨给建议者贴不同的 标签,对建议采纳的影响及其心理机制等。

2.4 其它因素对决策者认知加工的影响

决策者作为建议采纳的主体,其自身的许多 特征也会显著影响建议采纳,因此同样的建议产 生的说服效果不仅因情况而异,也因人而异,比如 自恋的人更不愿意寻求和采纳别人的建议(Kramer, 2016; Kausel et al., 2015)。除了个性特征, 决策者 的情绪也是一个重要的影响因素,很多研究都强 调了情绪在人们认知和决策等方面的重要作用 (Lerner, Li, Valdesolo, & Kassam, 2015)。例如, 当 决策者产生焦虑情绪时,会降低其自信程度,在 做决策时更喜欢寻求外界的帮助,并依赖他人建 议(Gino, Brooks, & Schweitzer, 2012; Jung & Young, 2012); 决策者的预期后悔情绪也同样会影响建议 采纳、采纳错误建议带来的后悔情绪会降低决策 者后期的建议采纳意愿, 而忽视正确建议的后悔 情绪会提高决策者后期建议采纳意愿(Tzini & Jain, 2017); de Hooge, Verlegh 和 Tzioti (2014)则发现, 决策者的归因方式影响了情绪和建议采纳的关系, 他人归因时积极情绪(感激)比消极情绪(生气)更 利于建议采纳;而当自我归因时,出现了反转现 象, 消极情绪(内疚)比积极情绪(骄傲)更利于建议 采纳。情绪影响建议采纳的认知机制是学者们一 直热衷的研究课题,但从信息加工的角度探讨焦 虑情绪的研究尚存在争议, 焦虑对建议采纳的认 知加工机制有待进一步明确(朱月龙,张开华,段 锦云,2017)。

早期有关权力如何影响建议采纳的研究一致 发现,相比于低权力者,高权力者更不易采纳他 人建议,因为高权力者更加自信,更容易忽视和 不信任他人(Mourali & Yang, 2013; See, Morrison, Rothman, & Soll, 2011; Tost, Gino, & Larrick, 2012, 2013)。近来的研究从认知角度对此结论提出了质 疑,de Wit, Scheepers, Ellemers, Sassenbegr 和 Scholl (2017)从权力的建构角度探讨了权力对建 议采纳的影响,发现将权力看作机会的个体更不 容易采纳建议,而将权力看作责任的个体则更倾 向于采纳他人建议。还有研究发现,睡眠剥夺(24 小时不闭眼睡觉)者更易采纳建议(Häusser, Leder, Ketturat, Dresler, & Faber, 2016),从认知的角度来 解释,睡眠不足会损害认知功能,从而损害个体 的注意力和记忆力,导致认知加工水平降低(Lim & Dinges, 2010),从而盲从建议。

随着网络技术的不断发展和普及, 越来越多 的人开始在网上咨询专业意见, Nguyen, Dabbish 和 Kiesler (2015)发现, 在个人主页上展示建议者 在此领域的工作活动时,能提高其可信度,继而 促进他人的建议采纳; 而主页上只呈现与工作无 关的活动时、建议采纳程度则会降低。但在控制 两位建议者的可信度之后,在个人主页上展示与 工作无关的活动时也能促进建议采纳,这可能是 在可信度明确且相同的情况下,其他无关信息的 展示提高了决策者对建议者的熟悉和了解,从而 促进建议采纳;也有研究发现,决策者认为高解 释水平的建议者更像专家, 更具能力, 也更喜欢 他们的建议(Reyt, Wiesenfeld, & Trope, 2016), 这 些研究都表明, 建议者方面的微妙线索特征有助 于决策者形成对建议者的整体判断,并影响最终 的建议采纳程度(Reyt, Batia, & Trope, 2016; 孙露 莹, 陈琳, 段锦云, 2017)。

由此可见,近年来学者们开始聚焦个体认知 差异来探讨建议采纳的影响因素,这无疑有助于 拓展建议采纳领域研究,也促使更多的研究者关 注比个体差异更深层的认知因素。

3 建议采纳认知机制模型建构及理论 基础

上述以往研究从微观视角阐述了以往实证研 究结果,那么建议采纳中的认知机制或理论如 何?本部分将结合行为决策领域的相关认知理论, 包括态度改变理论、解释水平理论、具身认知理 论和认知失调理论,对建议采纳的认知过程进行 分析和阐述,并尝试建构建议采纳的认知机制模 型,以期获得宏观层面的整体理解。

3.1 态度改变理论

态度改变指在接受某一信息的影响后,个体 对事物已经形成的态度会产生相应变化。态度改 变理论认为,当后期获得的信息与自己早前的意 愿相差甚远时,个体往往都会坚持自己的看法 (Sherman & Cohen, 2010)。因此,在做决策时,个 体倾向于坚持自己的初始观点,并且随着建议和 决策者初始观点的差距增大,建议被赋予的权重 会随之降低。态度改变的解释机制是基于认知加 工系统,早期的认知加工系统主要包括双系统模 型和精细加工可能性模型 (the elaboration likelihood model, ELM)。双系统模型包括基于直觉的启发式 系统和基于理性的分析式系统。在启发式系统中, 信息加工特点表现为速度快、自动化的、内隐的、 欠考虑的;而在分析式系统中,信息加工特点表现 为速度慢、受控制的、有意识的、基于规则的、深 思熟虑的(Kahneman, 2003; Kruglanski & Gigerenzer, 2011)。与此不同, ELM 提出用信息加工的中心路 线和边缘路线来解释态度改变。中心路线(central route)指个体通过详细的认知加工过程,对信息 进行深度加工,仔细思考和评判信息以及分析周 边线索;边缘路线(peripheral route)则类似于启发 式系统,对信息加工较粗糙,通过捷径快速的发 生态度改变。

不论是双加工模型还是精细加工可能性模型, 都依赖于信息加工深度和决策者的认知能力及认 知资源的投入, 当个体具有较强的认知动机和能 力时, 倾向于采用分析式或中心路线加工信息, 加工速度慢,需要投入更多的认知资源;而当个 体认知动机和能力均不强时,更多采用启发式或 边缘路线加工速度快,需要较少的认知资源。不 同的加工方式影响着个体的态度改变和最终决 策。如 Lim 和 Dinges (2010)基于认知加工模型探 讨建议采纳的认知机制,他们认为那些影响建议 采纳的因素会降低或提高个体的认知加工水平, 在此理论基础上, Pfundmair, Aydin 和 Frey (2016) 等人发现相比那些被接纳的个体, 被他人排斥过 的个体更容易被低质量的信息说服,这可能是因 为排斥经历导致了认知缺陷, 使个体缺乏认知动 机,在决策过程中,更依赖外界信息,而不过多 的评估建议质量,从而提高建议采纳。

3.2 解释水平理论

解释水平是个体认知表征的一个重要描述符号,认知表征可以由低解释水平到高解释水平进行组织。该理论认为,从语言风格能够推断出 其解释水平(Vallacher & Wegner, 1989)。Reyt 和 Wiesenfeld (2015)认为通过评估人们对活动的描述可以判断他们的解释水平,低解释水平注重事 情如何做(how);高解释水平注重为什么要这么 做(why)(Trope & Liberman, 2010)。人们的心理表 征是从低解释水平到高解释水平的连续体,高解 释水平会使个体与情境的心理距离更远(Trope & Liberman, 2010)。 先前研究表明建议者和决策者心理倾向会影 响建议采纳(Danziger, Montal, & Barkan, 2012)。 Danziger 等(2012)发现,由于他们与决策的心理 距离更远,建议者对问题的陈述往往比决策者更 抽象。van Swol和 Sniezek (2005)提出建议采纳取 决于决策者对建议者的评价,有研究发现语言抽 象性与他人对自己能力的认知密切相关(Wakslak, Smith, & Han, 2014; Palmeira, 2015)。Reyt 等人 (2016)从建议者解释水平的角度研究其对建议采 纳的影响,结果发现,高解释水平的建议者更可 能被认为是专家,更有能力,其建议也就更容易 被采纳。这也证明了建议者的解释水平影响了决 策者对其的认知,从而影响了建议采纳。

3.3 具身认知理论

具身认知理论(embodied cognition theory)认 为身体的形态结构、感觉系统、运动系统以及 表征身体的神经系统均会影响人们的认知加工 (Glenberg, 2010; Goldman & de Vignemont, 2009). 简而言之, 认知是我们的身体、大脑同环境相互 作用的结果(Borkent, 2015),也就是说,我们的一 颦一笑, 甚至温度的变化等都会影响到我们对事 物的认知加工。有研究发现在让被试进行书面自 我报告时,相比于在结尾处签名,在开头处签名 能够减少被试不诚实的报告(Shu, Mazar, Gino, Ariely, & Bazerman, 2012); 除此之外, 咖啡温度 (温热 vs 冰冷)会影响到个体对他人友善程度的感 知(Williams & Bargh, 2008), 但这种影响会受到 双方关系性质的调节,具体表现为当对方是假想 的竞争对手时,相比于手握冰冷咖啡,手握温热 咖啡的被试认为其对手更友善,而当对方是假想 的合作伙伴时,咖啡温度对搭档友善度的感知影 响并不显著(Citron & Goldberg, 2014)。这可能是 因为人们对温度和友善的认知是有共同特征的, 友善的人具备温暖的特质, 所以温热的咖啡能够 提高个体对他人友善的感知,而冰冷恰恰相反。这 也说明了感觉系统影响了我们的认知加工(Kaspar, Krapp, & König, 2015)。基于建议者的善意程度与 建议采纳是正向关系(张艳梅, 杜修芳, 王修欣, 2015), 我们可以推测, 如果建议者在提建议前递 给决策者一杯温热的咖啡,会促使决策者对其做 出更友善的评价,从而促进建议采纳,未来研究 可以进一步去验证两者的关系。

3.4 认知失调理论

认知失调理论(cognitive dissonance)最早由 Festinger 提出, 该理论认为在一般情况下, 人们 往往会因为生活中的各种不一致而感到难受,为 了能将这种不一致的失调感受调节到最低.人们 往往会努力去减少这些不协调, 寻求一种稳定的 感受。因此,当自己原有的认知信念和后期获得 的信息不符的时候,就会体验到认知失调(Festinger, 1957)。认知失调理论自提出以来备受青睐,也被 广泛的应用到行为决策领域,用来解释态度产生 和行为改变(Hinojosa, Gardner, Walker, Cogliser, & Gullifor, 2017)。在 JAS 系统中, 当人们感知到 建议和早期的成本不符时,认知就会产生失调, 人们很可能将建议视为有价值的,以此来调节自 己的认知失调,这也就解释了那些即使很平庸的 付费建议也更容易被采纳的原因。如前所述,段 锦云等(2014)发现在公开场合下建议人们参加无 报酬的活动时, 启动决策者正面自我标签能够促 进建议采纳,其原因在于启动正面标签后,决策 者对自己的形象产生了一个积极的认知,相比于 参加无报酬活动的建议,人们更喜欢采纳让其参 加有报酬活动的建议,因此对于参与无报酬活动 的建议,人们的潜在认知是不想采纳的,但由于 在公开的场合下,又被贴上了正面标签,此时就 会出现认知失调,为了维护好自己的正面形象, 决策者可能会改变自己的态度和行为,从而增加 建议采纳。

综上所述,态度改变、解释水平、具身认知 和认知失调理论都是基于个体的认知加工方式来 探讨建议采纳的发生机制。此外, Sniezek, Schrah 和 Dalal (2004)的研究验证了心理契约在建议采 纳中的作用,他们通过操控建议者知识和金钱报 酬分配时间, 使其产生心理契约, 结果发现心理 契约对于建议采纳程度和决策质量有着显著的影 响。沉没成本是指由过去的决策带来的现在或将 来都无法改变决策的成本,我们把这些已经发生 不可收回的支出,称为沉没成本效应(Thaler, 1980)。如果在决策之前,对建议投入了成本,即 使建议质量不高,决策者也会倾向于采纳有成本 的建议(Gino, 2008), 与沉没成本相吻合。虽然心 理契约理论与沉没成本理论分别从社会交换的角 度和对成本和收益衡量的角度解释建议采纳的发 生机制,但并未过多涉及深层次的认知加工,在

此就不过多赘述。

整合以往研究可发现,在理解建议采纳的认 知机制中,信息的作用十分关键,不论是认知风 格、社会认知复杂性、认知策略还是情绪,本质 上都是通过影响信息的产生、传递、接受与分析 过程而作用于建议采纳。包括态度改变理论在内 的理论解释,也是对决策过程中的信息进行有所 偏重的整合分析。结合对已有文献的梳理以及对 相关理论的阐述,我们初步构建了建议采纳认知 机制模型,见图 1。

首先,决策者本身的认知特征会影响到信息 加工方式,例如场依存型认知方式或认知复杂性 低的个体多采用启发式(边缘路线)分析和评估信 息,而场独立型和认知复杂性高的个体多采用分 析式(中心路线)分析和评估信息;此外,Duan,Xia 和 van Swol (2018)发现,低认知需要的决策者更 容易采纳包含表情符号的建议,这也进一步说明, 在决策过程中,低认知动机的决策者其认知加工 走的是边缘路线,决策者容易被一些表面特征所 吸引,如信息源特征、情感线索、表情符号等(Till & Michael, 2000; Tormala, Brinol, & Pett, 2006), 从而促进建议采纳。

其次,决策者的情绪、权力以及社会经历等 也会影响到自身的认知动机以及对建议内容或建 议者的认知评价,从而影响建议采纳;情绪和认 知是双向互动的,除了外在的情境特征会引发不 同情绪外,个体的认知动机、能力等同样会影响 到决策时的情绪,而情绪也会反过来影响决策者 的认知动机和能力及进一步的信息加工等,除此 之外,情绪也可能直接作用于建议采纳。

从建议者的角度来说,其认知方式会影响建 议提出(经验型 vs.分析型),解释水平以及个人信 息的展示会影响决策者对其专业性和可信度的评 估,进而影响建议采纳。不难发现,不管是来自于 建议者还是决策者的认知特征以及情绪,都共同 作用于认知评估过程,最终影响建议采纳。

4 总结与展望

建议采纳的认知因素远不止这些,从以上的 归纳中可发现,仍然有许多疑问在过去的研究中 并没有解释清楚。在未来研究中,可以进一步深 入分析并完善模型,例如,决策者的认知闭合需 要、认知灵活性与建议采纳的关系,以及建议提 出的认知机制,等等。

4.1 认知闭合需要与建议采纳

前人研究从认知风格、认知复杂性、认知策 略等角度讨论了认知对建议采纳的影响,但目前 还未有学者从认知动机的方向展开研究,作为认 知动机的认知闭合需要(need for cognitive closure) 一定对建议采纳发生影响。根据 Kruglanski (1993) 的定义,认知闭合需要是指个体应对模糊性和不 确定性情境时表现出的快速而坚定的做出决策的 动机和愿望。高认知闭合需要的个体对模糊性的 容忍度较低,会产生更多的压力和焦虑情绪,所 以即使在没有充足证据的情况下也会选择立即决 策,以此来缓解压力和焦虑;与此相反,低认知



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闭合者对模糊性的容忍程度较高,在面对模糊性 情境时产生的焦虑较轻, 不急于立刻消除不确定 性,他们会倾向于延迟做出决策,因此具有更强烈 的动机进一步搜集相关信息或者对信息进行更深入 地分析和思考, 以期决策最优(Jasko, Czernatowicz-Kukuczka, Kossowska, & Czarna, 2015)。除此之外, 认知闭合还影响到人际信任, Acar-Burkay, Fennis 和 Warlop (2014)在其研究中发现认知闭合和人际 亲密度交互影响人际信任,相比陌生人,高认知 闭合需要者会更信任亲近的人(朋友); 但对于低 认知闭合者,人际亲密度并不影响其信任程度。 那么可以推测,在决策情境中,高认知闭合者由 于缺乏认知动机,对问题模糊性的容忍度低,迫 切需要解决问题消除不确定感,而倾向于采纳 建议,未来研究可以进一步研究认知闭合对建议 采纳的影响以及是否会受到人际亲密度等因素的 调节。

4.2 认知灵活性与建议采纳

如前文所述,决策者的认知策略会直接影响 建议采纳, 而认知灵活性反映的是个体能够采取 认知加工策略来适应变化多端的环境的能力,所 以也必然会影响决策者的行为表现。认知灵活性 包含三层含义:一是在任何环境下都能意识到自 己有多种选择; 二是能够灵活的适应环境; 三是 坚信自己具备灵活处理事情的能力(Martin & Rubin, 1995)。认知灵活性高的个体对自己的行为表现更 加自信(Bandura, 1978)。认知灵活性与情绪相互作 用、通常积极情绪下的个体以满意化的结果为目 标,运用自上而下的信息加工策略,这种信息加 工策略提高了发散思维能力和认知灵活性。消极 情绪下的个体以最优化的结果为目标,采用自下 而上的信息加工策略,关注环境信息的细节,将 注意力局限于当前刺激物的细节信息,这种信 息加工策略降低了发散思维能力和认知灵活性 (George & Zhou, 2002)。在积极情绪的作用下, 认 知灵活性也会相应地提高,从而有利于形成正确 的决策。由于高认知灵活性表现为较强的思维发 散能力和注意转换能力,从信息加工的角度来说, 认知灵活性高的个体多采用自上而下加工策略, 注意转换能力强。因此在决策环境中面对众多建 议时, 高认知灵活性者对建议的信息加工和整合 能力也相对较高,可以不局限于环境信息,从而 降低了建议采纳程度。未来研究可以就此猜想进

一步探讨认知灵活性与建议采纳的关系,同时研 究情绪的调节作用。

4.3 建议提出的认知机制

为了使决策最优化,我们常常不止从一方获 取建议, 当存在多个建议者时, 除了建议者本身 能力外,建议者的认知偏差也会影响到建议的质 量,从而影响建议采纳。那么在什么情况下第二 建议者的存在对决策者来说是有益的,什么时候 又是不利的? Sah 和 Loewenstein (2015)对此展开 了一系列研究,发现当第一建议者意识到决策者 有第二建议可获得时,他们就会启动自利模式, 给出更有偏差的建议;当第一建议者认为第二建 议是低质量时,会加剧建议偏差;当第二建议是 高质量并且容易获得时, 第一建议者会减小建议 偏差。这可能是因为当有其他可获得的资源或建 议时, 第一建议者的职业道德感、责任感会被忽 视,而启用自我受益模式。也就是说,第二建议的 质量和可获得性会影响到第一建议者的认知偏差, 从而启动自利模式或者道德模式,继而影响到建 议质量。

虽然真诚的、高质量的建议会提高决策质 量,但并非每一条真诚的建议都会被采纳(Sah & Loewenstein, 2014, 2015; Sah, Loewenstein, & Cain, 2013),当建议被决策者拒绝时,建议者的社会价 值感会降低,这会导致建议者减少亲社会行为, 并在随后的交流中给出不诚实的建议,但如果决 策者在拒绝建议时表达出感激之情,则会减少这 种效应(Belkin & Kong, 2018),这说明决策者对建 议的态度会直接影响到建议者后期建议的质量。 以往研究还发现文化差异(Chentsova-Dutton & Vaughn, 2012)和情感支持(Feng, 2008)等因素都会 影响建议提出(孙露莹等, 2017)。未来研究还可继 续探讨诸如建议者情绪、其它的环境因素等是否 会影响建议者产生认知偏差,从而提出有偏差的 建议等议题。

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The cognitive mechanism of advice taking

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Abstract: This article reviews the research of the relationship between cognition and advice taking in recent years. The advisor, task characteristics and the situation will affect the adoption of advice through the cognitive process of decision maker. Firstly, this article briefly introduced antecedent variables. Based on previous research, we summarized cognitive factors which affect advice taking in four aspects-cognitive style, cognitive complexity, cognitive strategy and emotion. Then we tried to explain the mechanism of advice taking through four theories, which are attitude change theory, construal level theory, embodied cognition theory and cognitive dissonance theory. By analyzing the cognitive factors which mentioned above, we attempted to put forward the comprehensive model of cognitive mechanism. Finally, the article suggests that future research can enrich advice taking in following aspects, the effect of cognitive flexibility of decision makers, the need for cognitive closure on advice adoption and the cognitive mechanism of advice giving.

Key words: advice taking; cognitive mechanism; attitude change theory; construal level theory; embodied cognition theory; cognitive dissonance theory

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企业组织中管理者变革担当的涓滴效应: 跨层次被调节的中介模型

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摘 要:基于社会学习理论,采用 315 份主管一下属配对数据 构建了管理者变革担当对下属变革担当的涓 滴模型,并考察了奖励预期和风险知觉的中介作用以及变革担当效能信念的调节作用。跨层次结构方程模型数 据分析结果表明:管理者变革担当对下属变革担当有显著正向影响;奖励预期和风险知觉在管理者变革担当与 下属变革担当的关系中起着完全中介作用;变革担当效能信念不仅正向调节奖励预期影响下属变革担当的关 系,还进一步调节管理者变革担当通过奖励预期影响下属变革担当的间接效应,但变革担当效能信念对风险知 觉和下属变革担当之间关系的调节作用不显著。

关键词: 变革担当; 奖励预期; 风险知觉; 变革担当效能信念

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一、引言

员工的变革行为对于组织的发展极为重要, 是组织获得竞争优势和成功的关键。^{[1][2]}随着经济 全球化竞争的加剧,组织面临的环境和任务不确 定性逐渐增加,越来越多的企业管理者意识到激 发员工变革行为的重要性。究竟何种领导行为最

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有利于促进员工的变革创新?我国自古以来就强 调为政者应身体力行,率先垂范,当代领导理论, 如自我牺牲型领导、道德领导、变革型领导也都证 实了人们对领导者德行垂范的重视。^{[3][4][5]}我们认 为在企业组织中,领导者或管理者对于具体工作 行为的榜样示范作用具有非常重要的意义。特别 当这种工作行为具有"除旧革新"的性质,如组织 中的一些制度或程序已经过时需要变革时,管理 者自上而下的支持尤其是身体力行的直接示范, 对于下属主动解决问题和寻求改进的工作行为将 能够起到极大的鼓励和促进作用。

西方学者将员工自发地对工作方法、政策、程 序等进行变革以提升工作效率或组织效能的角色 外工 作 表 现 称 为 变 革 导 向 型 组 织 公 民 行 为 (change-oriented OCB,以下简称为"变革导向行 为")。^[6] 变革担当(taking charge) 是变革导向行为 的一种,最早由 Morrison 等提出,指的是员工自愿 付出建设性努力来发起组织功能性变革,以便在 自己的岗位、部门或组织情境下更加有效地开展 工作。^{□1}它所聚焦的是积极或建设性的变革── 不仅识别出需要变革的问题和机会,而且采取行 动对工作方法、政策、程序做出实际改变。[7]变革 担当概念提出以来,其影响因素和影响后果成为 学者们关注的重点。研究证实了前瞻性人格、自 我效能感、变革责任知觉、积极情感等个体因素与 变革担当行为存在显著相关性^{[8][9][10][11]};此外,工 作设计(如工作自主性)、领导风格(如变革型领 导,自我牺牲型领导)、领导——成员交换关系等情 境因素也对变革担当的形成与变化产生影 响。[12][13][14][15]关于变革担当行为的影响后果,现 有研究主要关注了员工变革担当行为与主管对员 工工作绩效评价之间的关系以及变革担当与工作 态度的关系等方面。[15][16]

通过文献回顾,可以发现,以往研究在变革担 当的行为主体方面,无一例外都是聚焦于员工或 下属的变革担当表现。然而在组织中处于较高地 位的管理者,其变革担当行为所产生的榜样示范 效应,应能带来更大范围的影响。但到目前为止, 尚未有直接聚焦于管理者变革担当行为的研究。 中国是一个高权力距离国家,注重等级制度,因而 在企业组织中,管理者通常成为下属模仿学习的 榜样。因此,根据社会学习理论,本研究构建了管 理者变革担当对下属变革担当的涓滴效应模型 (trickle-down model)^①。具体而言,我们从学习动 机和学习能力两个方面探讨管理者变革担当对下 属变革担当的影响机制,首先聚焦于下属对变革 担当行为的奖励预期和风险知觉这两个反映动机 因素的变量 构建双中介路径,之后纳入下属变革 担当效能信念这一调节变量,以期尽可能全面地 揭示个体的能力因素对中介过程的权变影响。另 外,本研究中管理者变革担当属于部门层面变量, 我们采用跨层次分析方法进行分析,不仅可以提 高研究结果的准确性,也进一步增强了研究结论 的外部效度。本研究结果一方面丰富和拓展了变 革导向行为特别是变革担当行为的理论研究,另 一方面也可以有效指导组织变革与创新管理的 实践。

二、理论基础与研究假设

(一) 变革担当

根据 Morrison 等^[1]的界定,变革担当是指员工 自愿付出建设性努力来发起组织功能性变革,以 便在自己的岗位、部门或组织情境下更加有效地 开展工作。典型的变革担当行为如: 消除多余或 不必要的程序 引进新的方法以改进效率 改变对 绩效无益或阻碍绩效的组织规则及政策等。变革 担当具有以下几个特点:(1)自发性。变革担当是 自主决定和自发做出的,而不是被要求的。[15](2) 变革导向。变革担当行为本质是变革导向的,是 对现状或现行做法进行建设性的改变。(3)挑战 性和风险性。变革担当行为打破或改变了现状, 有可能会遭到不同层面人士的反对,因此具有挑 战性和风险性。另外,变革担当也不同于其他变 革导向行为,如建言,创新行为。与建言行为主要 聚焦于建议或想法的沟通相比 变革担当更注重于 积极努力的实施变革,行动性更强;^[20]与创新行为 主要聚焦于新思想、新技术相比,变革担当具有更 宽的范畴 强调实际行动 不限于新想法或观点。[7]

①在组织管理领域, 涓滴效应又称之为下行传递效应, 是指某 种特定的行为、知觉或体验由上而下逐层扩散的现象。^[17] 有关涓 滴效应的研究中, 一些研究者设计了三个层次(如"上司→目标 管理者→下属"), 但这些研究均无法再考察涓滴效应的内在机 制。为了实证检验管理者变革担当行为涓滴效应的内在机制,本 研究采用 Tepper, B.I., Taylor, E.C.和W, D.等的做法, 仅设计两个 层次"目标管理者→下属")。^{[18][19]}

(二)管理者变革担当与下属变革担当

根据社会学习理论,人类的大多数行为都是 通过观察而学习的。^[21]领导学研究则进一步表明 通过观察领导者行为的替代性学习在塑造下属行 为方面发挥着关键性作用。^[4]管理者在组织中较 高的身份地位及权威性,使得下属将他们视为学 习的榜样并对其行为进行观察及效仿,产生下行 传递效应。^{[22][23]}Tepper等研究发现,领导的组织 公民行为通过提升下属的程序公平感,促使下属 表现出更多的组织公民行为。^[18]Yaffe等^[24]指出, 管理者的亲和型组织公民行为能够显著促进群体 的同类行为表现。具体到本研究的变革担当行 为,我们认为管理者的变革担当会传递给下属。

首先,变革担当往往涉及对现有程序和做法 的改变或挑战,其风险性特征使得员工在从事此 类行为时心存疑虑,此时,管理者亲身示范的榜样 作用将具有重要意义。当下属观察到管理者展现 出较多的变革担当行为时,员工会感到变革担当 行为是恰当的,有价值的,这将能有效消除员工对 于该行为可能造成的风险性后果的顾虑与担忧, 从而学习和模仿管理者做出类似的行为。这在集 体主义文化情景下会显得更为突出,因为这种文 化更强调人的互依性,群体嵌入性,个体更容易受 到他人行为的影响,管理者作为下属的"重要他 人",其变革担当行为更能激发下属做出类似的 行为。

其次,管理者通常是组织规则的制定者,也是 组织资源的分配者,下属可以通过领导的奖罚措施,了解哪些行为是与组织的价值观相一致,这种 间接经验的获取将有利于引导下属的行动方向, 提高员工的变革担当行为。

最后,重视变革担当行为的管理者,在与下属员工进行日常交流和互动过程中,会强调变革担当行为对组织部门运作的重要性,这种口头说服也会对员工从事变革担当行为产生正面影响。以往的研究证实了员工的创造力自我效能感会受到领导口头说服的影响^[25],具有高情感承诺的领导会通过口头说服,来提高员工对组织的情感承诺。^[26]因此,提出假设:

H1:管理者变革担当对下属变革担当存在显 著的正向影响。

(三) 奖励预期和风险知觉的中介作用 社会学习理论认为,人们在何种程度上模仿

特定行为取决于四个因素:注意(观察行为)、保持 (记得自己所观察到的行为)、再现(有能力重现该 行为)和动机(做出该行为的充分理由)。^[21]就能 力而言 变革担当的变革性和复杂性使之对行为 者的相关认知和行为能力具有较高的要求,变革 担当效能信念即反映了与此密切关联的个体差 异。就动机而言,人们通常希望获得积极的学习 结果并避免消极的学习结果。[27]本研究中,奖励预 期和风险知觉即对应着追求积极结果和避免消极 结果这两种观察学习过程中的重要动机。那么, 能力与动机哪个更应成为管理者变革担当与下属 变革担当之间的主要中介路径呢? Bandura^[27]认 为通过观察学习而提升行为能力的一个重要条件 是观察者与榜样之间的相似性 比如组织中身处 相同职级的同事,他们有着相似的资历、经验,通 过观察和模仿同侪的行为,自己对实施该行为的 能力也会更加自信。而本研究中,观察者(下属) 与榜样(管理者)处于不同的职级,在中国的高权 力距离文化下,上下级是典型的层级关系,领导的 变革担当行为会被下属更多地解读为组织的价值 取向 在此基础上 下属会进一步预测该行为会带 来什么 形成结果预期。结果预期对于行为的呈 现具有极为重要的作用,个体通过事先判断某项 行为可能带来的结果,再对其随后的行为进行调 整。期望理论认为,当员工认识到自己的行为可 以获得对自己有价值的结果时,就会投入到这种 行为中。^[28]因此,本研究预期,在上下有别、上尊下 卑的传统文化影响情境下,管理者变革担当与下 属变革担当之间起主要中介作用的是下属的动机 而非效能信念。

本研究中,奖励预期是指个体对于变革担当 行为将能为行动者带来奖励的可能性大小的知觉 和判断。根据社会学习理论,作为模仿过程的结 果,个体认识到某些具体行为是合适的并有可能 被奖励,则倾向于做出类似的行为。社会信息加 工理论认为,员工会受到组织中各种信息线索的 影响,进而表现某些反应。^[29]鉴于管理者在组织 中所处的较高地位,当管理者展现出变革担当行 为时,下属会给与积极正面的解读,即变革担当表 现应是组织提倡和鼓励的,体现了组织的价值导 向,从而形成较高的奖励预期。另一方面,行为心 理学家认为个体对额外的付出具有天生厌恶性, 其行为会受到积极结果的引导与激励。^[30]变革担 当属于角色外行为,其复杂性和风险性特征使得

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员工需要消耗更多的脑力、体力等资源,较高的奖励预期能够让员工意识到付出更多努力背后的潜在收益与发展机会,从而为变革担当行为提供正面反馈和强化机制,提升员工内在动机,激发变革担当行为。因此,提出假设:

H2a: 奖励预期在管理者变革担当与下属变革 担当之间起中介作用。

本研究中,风险知觉是指个体对与变革担当 相联系的人际风险或负性后果的感知和判断。变 革担当超越了既有的规范或角色要求,并包含对 现状的改变或挑战,¹¹因此这类行为容易造成人 际冲突和损害人际关系。^[20]在高度重视关系和人 际和谐的中国社会背景下,这无疑是人们非常担 心或忌惮的。管理者的变革担当应能影响下属对 此种行为的风险知觉。因为管理者变革担当会在 很大程度上反映出管理者及其所代表的组织对此 种行为的积极或肯定态度,从而应会降低下属对 该行为的风险知觉。另一方面,计划行为理论认 为,个体的行为取决于其行为意愿,在做出某种行 为前,一般会对该行为的风险进行评估。Wei 等^[3]研究发现感知到的风险与建言行为显著负相 关。当下属对变革担当的风险知觉较低时,变革 担当通常会被认为是有价值的 ,在这种情况下 ,个 体做出变革担当行为的可能性则会增加;反之,他 们会规避风险而拒绝实施该行为。因此,提出 假设:

H2b:风险知觉在管理者变革担当与下属变革 担当之间起中介作用。

(四) 变革担当效能信念的调节作用

尽管较高的奖励预期和较低的风险知觉是促 使个体做出变革担当行为的重要认知条件,但个 体是否有能力再现特定行为,会影响他们是否模 仿该行为。^[32]效能信念则对应着个体从事某项行 为的能力因素。在工作场所中,员工既存在一般 性的效能信念,即个体对完成某项工作任务所具 备的能力的自信程度,也会针对不同类型的工作 行为发展出相应的效能信念,并且在预测员工的 特定行为时,具体性效能信念比一般性效能信念 要更为准确和有效。^[33]本研究中,变革担当效能信 之指的即是个体对于其从事变革担当行为的能力 知觉或信念。以往研究发现自我效能信念对变革 导向行为影响显著。^{[7][34]} Parker等^[8]提出了变革 导向行为的能力(can do) 路径,即自我效能信念对 包括变革担当在内的变革导向行为具有促进作 用。我们认为,变革担当行为包含了对现状的改变 或挑战,具有风险性和复杂性,动机因素和能力因 素需同时满足,个体才更有可能展现此类行为。 当下属的变革担当效能信念较高时,他们会相信 自己有足够的能力实施变革并获得成功,而且他 们会认为自己的变革努力是有意义和价值的。这 时,变革担当效能信念有助于将下属的高奖励预 期和低风险知觉推向变革担当行为的选择,因而 更有可能展现出变革担当行为的选择,因而 更有可能展现出变革担当行为。相反,当下属的 变革担当效能信念较低时,他们会对自己实施变 革担当行为信心不足,对于变革努力的意义感知 也会较低,因此即使下属对变革担当行为的奖励 预期较高,或风险知觉较小,他们做出该行为的可 能性仍然会较小。因此,提出假设:

H3a: 下属变革担当效能信念正向调节下属奖 励预期与变革担当行为之间的关系,即下属的变 革担当效能信念越高,这一关系越强。

H4a: 下属变革担当效能信念正向调节下属风 险知觉与变革担当行为之间的关系,即下属的变 革担当效能信念越高,这一关系越强。

结合假设 2a、2b 和假设 3a、4a 所涉及的关系 本研究进一步推断,下属变革担当效能信念对奖 励预期和风险知觉在管理者变革担当与下属变革 担当之间的中介作用也存在调节效应,即构成被 调节的中介作用。具体而言,当下属变革担当效 能信念较高时,奖励预期和风险知觉对下属变革 担当的影响较大,管理者变革担当经由奖励预期 和风险知觉的中介作用而对下属变革担当行为产 生的间接影响也会相应增强。相反,当下属的变 革担当效能信念较低时,奖励预期及风险知觉与 下属变革担当之间的关系较弱,通过奖励预期和 风险知觉而传导的管理者变革担当对下属变革担 当的间接效应也就相应较小。因此,提出假设:

H3b: 下属变革担当效能信念正向调节奖励预 期对管理者变革担当与下属变革担当之间关系的 中介作用,即下属变革担当效能信念越高,这一中 介作用越强。

H4b: 下属变革担当效能信念正向调节风险知 觉对管理者变革担当与下属变革担当之间关系的 中介作用,即下属变革担当效能信念越高,这一中 介作用越强。

综上所述,本研究的理论模型如图1所示。

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图1 理论模型

三、研究方法

(一)数据收集

本研究采用问卷调查法收集数据,调查对象 为来自苏南地区的8家高科技企业。为避免共同 方法偏差的影响,研究者通过两种来源并以下 属-主管配对的方式进行数据的收集 最终确定 了 109 名主管及 369 名下属作为调查对象。研究 采用嵌套式问卷,一套问卷包含一份主管问卷和 若干份直接下属问卷。发放问卷前,将主管问卷 和下属问卷分别放入小信封内,再将小信封放入 大信封,每个信封都事先贴好双面胶带。问卷中 简要介绍了此次调查的目的 ,告知他们参与调查 是自愿的 研究结果仅用于科学研究 并承诺对其 所填写的信息绝对保密。发放问卷时,我们将主 管问卷发放给管理者,由其填写对下属变革担当 的评价。同时将下属问卷发给对应的员工填写, 包含对主管变革担当的评价以及变革担当奖励预 期、风险知觉和效能信念的自评,员工填好之后将 问卷放入小信封并封好交给直接主管,管理者收 齐问卷后连同自己填写的主管问卷一并放入大信 封交还给我们。最终收到了 364 名员工和 108 名 主管的调查问卷,剔除空白、漏答过多,明显乱填 的问卷,并经过下属—主管匹配之后,一共得到了 315 份配对数据(对应于 315 名员工和 94 名主 管)。

主管样本的基本构成情况如下: 性别方面,男 性占 60.6%,女性占 39.4%;年龄方面,以 30~39 岁和 40~49 岁为主,分别占 52.1%和 26.6%;受教 育程度方面,以大学本科学历为主,占 55.3%;工 作年限方面,以 7~10年和 10年以上居多,分别占 28.7%和 40.4%;职位层级中以中层管理者为主, 占 67%。 下属样本的基本构成如下: 性别方面,男性占 43.5%,女性占56.5%; 年龄方面,以20~39岁员 工居多,占比86.4%; 受教育程度方面,拥有大学 本科和专科学历的分别占47.6%和24.1%; 工作 年限方面,1~3年占33.7% A~6年占22.9%,7 年及以上的占29.6%; 职位层级中以普通员工和 基层管理者为主,分别占65.1%和29.5%。

(二)测量工具

为了确保测量工具的可信度,本研究主要选用过往文献中的成熟量表同时严格遵循翻译和回译的标准流程。^[35]所涉及量表均采用Likert五点评分法,管理者变革担当与下属变革担当评分范围从1(完全不同意)至5(完全同意),变革担当效能信念评分范围从1(非常不自信)至5(非常自信)奖励预期与风险知觉评分范围从1(非常不可能)至5(非常可能)。

管理者变革担当。参照 Li 等以及 Fuller 等^{[7][14]} ,从 Morrison 等单维度 10 题项变革担当量 表中选取因子载荷较高的 6 个题项。^[1] 该量表由 管理者的直接下属评价,题项内容如 "我的上司 经常尝试制订令部门/公司更具效率的新工作方 法",该量表的 Cronbach's α 系数为 0.934。

下属变革担当。与管理者变革担当量表类 (4) 选取 Morrison 等单维度 10 题项量表中因子载 荷较高的 6 个题项^[1],由管理者对其直接下属进 行评价。题项内容如"该下属经常尝试制订令部 门/公司更具效率的新工作方法",该量表的 Cronbach's α 系数为 0.900。

变革担当效能信念。参照 McAllister 等的做 法^[20],直接根据变革担当量表来编制,通过请下属 评估他们是否有能力做出具体的变革担当行为事 例来测量。题项内容如"尝试制订令部门/公司 更具效率的新工作方法,您对从事这一活动感到

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自信吗?"该量表的 Cronbach's α 系数为 0.890。

奖励预期。直接根据变革担当量表编制,通 过请下属评估具体的变革担当行为事例是否会受 到奖励来测量。题项内容如 "如果您尝试制订令 部门/公司更具效率的新工作方法,会受到奖励 吗?"该量表的 Cronbach's α 系数为 0.900。

风险知觉。参照 Wei 等的建言行为风险知觉 量表^[31],直接根据变革担当量表编制,通过请下属 评估具体的变革担当行为事例是否会产生消极后 果进行测量。题项内容如"如果您尝试制订令部 门/公司更具效率的新工作方法,会产生消极后果 吗?"该量表的 Cronbach's α 系数为 0.917。

控制变量。本研究选择了反映下属特征的人 口统计学变量作为控制变量,主要包括性别、年 龄、学历、职位和工作年限。

(三)分析方法

本研究理论模型中包含个体层面和团队层面 变量。个体层面的变量有奖励预期、风险知觉、变 革担当效能信念和下属变革担当;团队层面的变 量为管理者变革担当。为了确认管理者变革担当 能够作为团队层面变量加入模型,我们考察了相 关指标用以判断是否符合聚合条件。管理者变革 担当 R_{we}的平均值为 0.873,高于 0.70^[36],ICC(1) 为 0. 394, ICC (2) 为 0. 685, 分别大于 0.05 和 0. $5^{[37]}$,这些结果表明团队下属对管理者变革担 当的评分具有较高的一致性;因此,可以将个体层 面的数据聚合到团队层面。在检验假设之前,我 们检验了下属变革担当的组间差异。结果表明, 不同团队中下属的变革担当表现差异显著(F = 4. 243 $_{P}$ <0.001 JCC(1) = 0. 492);因此,我们有必 要采用跨层的方法来验证假设。本研究数据统计 分析的软件为 SPSS23.0 和 Mplus7.40。

四、数据分析与结果

(一) 变量区分效度检验

我们采用非可测潜在方法因子来检验是否存 在共同方法偏差效应。^[38]结果显示 在五因子模型 基础上增加一个共同方法因子后 ,CFI 和 TLI 只提 高了 0.008 和 0.006 ,RMSEA 只降低了 0.002 , SRMR 则升高了 0.005 ,表明模型的拟合指数并未 显著提高 ,本研究的共同方法偏差并不严重。进 一步的验证性因子分析结果如表 1 所示 ,五因子 模型与数据拟合度(X²/df = 2.00 ,RMSEA = 0.05 , SRMR=0.04 ,CFI=0.94 ,TLI=0.94) 最为理想 ,并 显著优于其他备选模型 ,说明五个变量之间的区 分效度也比较好 ,可以进行进一步的分析。

模型	χ^2	df	χ^2 / df	RMSEM	SRMR	CFI	TLI
五因子模型"	791.26	395	2.00	0.05	0.04	0.94	0.94
四因子模型 ^b	1261.34	399	3.16	0.08	0.06	0.87	0.86
三因子模型。	2566.97	402	6.39	0.13	0.15	0.68	0.66
二因子模型 ^d	3482.61	404	8.62	0.16	0.18	0.55	0.52
单因子模型 [。]	3977.28	405	9.82	0.17	0.15	0.48	0.44

表1 验证性因素分析

注:"假设模型;^b奖励预期和风险知觉合并为一个因子;^c管理者变革担当、奖励预期和风险知觉合并为一个因子;^d管理 者变革担当、奖励预期、风险知觉和变革担当效能信念合并为一个因子;^c五个变量合并为一个因子。

(二) 描述性统计分析

表2呈现了本研究涉及变量的描述性统计结 果,包括均值、标准差和相关系数。就自变量、中 介变量与结果变量之间的关系而言,管理者变革 担当与奖励预期(r=0.512,p<0.01)以及下属变 革担当(r=0.448,p<0.01)均显著正相关;奖励预 期与下属变革担当亦呈显著正相关(r=0.688,p< 0.01)。同时,管理者变革担当与风险知觉(r= -0.390, p<0.01) ,风险知觉与下属变革担当(r= -0.541 p< 0.01) 均显著负相关,这些结果初步支 持了本研究所提出的直接关系和中介效应相关 假设。

(三)假设检验

我们采用多层结构方程模型(MSEM)以及 Mplus7.4 来验证我们的假设。^[39]路径图如图2所 示 具体的路径系数如表3所示。

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变量	М	SD	1	2	3	4	5	6	7	8	9
性别	1.57	0.50									
年龄	2.71	0.75	0.059								
学历	3.29	0.96	-0.049	-0.349**							
职位	1.41	0.60	-0.121*	0.018	0.247 **						
工作年限	2.83	1.27	0.115*	0.530**	-0.134*	0.118^{*}					
管理者变革担当	3.83	0.50	-0.018	-0.111*	0.020	0.020	-0.048				
奖励预期	3.43	0.67	-0.121*	-0.011	-0.066	0.089	-0.029	0.512**			
风险知觉	2.14	0.70	0.027	-0.050	0.151 **	0.007	-0.036	-0.390**	-0.607 **		
变革担当 效能信念	3.11	0.57	-0.044	-0.054	0.016	0.098	-0.131*	-0.048	0.074	0.019	
下属变革担当	3.39	0.64	-0.071	0.007	-0.036	0.107	-0.030	0.448**	0.688**	-0.541 **	0.157**

表 2 变量均值、标准差及相关系数

注: N=315 M 为均值 ,SD 为标准差, * "和 "**" 分别表示在 5% 和 1% 水平上显著。





在控制了下属性别、年龄、学历、职位和工作 年限变量后,我们构建管理者变革担当对下属变 革担当的多水平回归模型,结果显示,管理者变革 担当对下属变革担当有显著的正向影响(γ = 0.575,p<0.001),假设1得以验证。表3呈现了 整体模型的路径分析结果,从表3可以看出,管理 者变革担当对下属奖励预期(γ =0.691,p<0.001) 有显著的正向影响,奖励预期亦显著正向影响下 属变革担当(γ =0.554,p<0.001);管理者变革担 当对风险知觉亦显著负向影响下属变革担当(γ =-0.311,p<0.001);同时,管理者变革担当对下 属变革担当的直接效应不显著(γ =-0.002,p> 0.05),说明奖励预期(γ =0.383,p<0.001)和风险 知觉(γ =0.180,p<0.01)在管理者变革担当和下属 变革担当之间起完全中介作用,假设 2a 和假设 2b 得到验证 蒙特卡洛模拟方法抽样 20000 次的检验 结果表明,奖励预期中介作用的 95% 置信区间 为[0.234 ρ .550],不包含 0,风险知觉中介作用的 95%置信区间为[0.077 ρ .301],不包含 0,且总间接 效应(al×b1+a2×b2)95% 置信区间为[0.379, 0.766]亦不包含 0。因此,假设 2a 和 2b 得到进一 步验证。此外 变革担当效能信念对奖励预期和下 属变革担当之间的关系起到正向调节作用(γ = 0.173 ρ <0.05),但对风险知觉和下属变革担当之 间关系的调节作用不显著(γ =-0.038 ρ >0.05);因 此,假设 3a 成立,假设 4a 没有得到验证,从而假设 4b 也不成立。结合行为决策领域有关人们对损失 的敏感性大于对收益的敏感性这一发现,我们推 断,风险知觉与下属变革担当行为的关系没有受到 变革担当效能信念的调节,原因可能是,感知到的 风险比预期的奖励更容易引起下属的重视,当下属 感知到变革担当有可能会给自己带来损失时,效能 信念高低与否对其行为决策将影响甚微。

路径	系数(标准差)	路径	系数(标准差)
al	0.691 ***(0.073)	a2	-0.580 ****(0.084)
b1	0.554 ***(0.101)	b2	-0.311 ****(0.086)
中介效应 1(a1×b1)	0.383 ***(0.075)	中介效应 2(a2×b2)	0.180**(0.059)
d1	0.173* (0.070)	d2	-0.038(0.080)
с	-0.002(0.075)	e1	-0.011(0.055)
e2	0.016(0.037)	e3	0.024(0.029)
e4	0.055(0.045)	e5	-0.011(0.020)

表 3 MSEM 路径分析结果

注 *" "**" "***" 分别表示在 10%、5% 和 1% 的水平上显著。

为了更直观的反映变革担当效能信念的调节 效应,我们参考 Aiken 等的做法^[40] 将变革担当效 能信念按照均值加减一个标准差,分别做奖励预 期对下属变革担当的回归分析,结果如图 3 所示。 从图 3 中可以看出,与低变革担当效能信念相比, 在高效能信念的情境下,奖励预期与下属变革担 当之间的正向关系更强,与预期相符。同时,我们 在效能信念的两个水平上(正负一个标准差)对调 节效应做简单斜率分析。结果表明,对于变革担 当效能信念较低的下属,奖励预期对其变革担当 行为的正向影响显著(β = 0.493, p < 0.001);对 于变革担当行为的正向影响更显著(β = 0.823, p < 0.001)。假设 3a 进一步得到验证。



表4显示了中介变量为奖励预期时被调节的 中介效应蒙特卡洛(抽样 20000次)检验的结果。 由表4可知 在变革担当效能信念较高的条件下,管 理者变革担当通过奖励预期影响下属变革担当的 间接效应为 0.451,95% 置信区间为[0.286, 0.628];在变革担当效能信念较低的条件下,管理 者变革担当通过奖励预期影响下属变革担当的间 接效应为 0.314,95% 置信区间为[0.159,0.479]; 组间差异值为 0.137,95% 置信区间为[0.024, 0.251] 达到显著性水平。由此可见,管理者变革 担当经由奖励预期对下属变革担当的间接效应受 到变革担当效能信念的调节,存在被调节的中介效 应,假设 3b 得到验证。

表 4 被调节的中介效应

结果 变量	变革担当 效能信念	效应值	标准 误差	下限	上限
下属变 革担当	高水平	0.451	0.090	0.286	0.628
	低水平	0.314	0.071	0.159	0.479
	高低差异	0.137	0.059	0.024	0.251

五、结论与讨论

(一)研究结论

本研究基于社会学习理论构建跨层次结构方 程模型,探讨了管理者变革担当影响下属变革担 当的中介机制及边界条件,得到以下主要结论。 首先,本研究证实了管理者变革担当对下属变革 担当的涓滴效应,即管理者作为下属的重要学习 榜样,所展现出来的变革担当行为能够有效促进

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下属的变革担当行为表现。其次,本研究证实了 奖励预期与风险知觉在管理者变革担当与下属变 革担当之间的中介作用,说明在受上下有别、上尊 下卑的传统文化影响背景下,动机是员工工作行 为表现的重要考量因素。最后,本研究发现,变革 担当效能信念对奖励预期与下属变革担当之间的 关系及其中介效应发挥了显著的调节作用,即当 下属的变革担当效能信念较高时,管理者变革担 当经由奖励预期对下属变革担当的影响更强。

(二)理论意义

首先,现有研究中变革导向行为的主体均为 员工或"管理者一下属"对偶角色中的下 属^{[13][14][15]},忽视了变革导向行为在人际(特别是 上下级)间的传导。本研究首次聚焦于管理者的 变革担当行为,通过将管理者角度和下属角度结 合起来,探讨变革担当行为是如何由上至下传递 给下属的.把以往只针对员工变革导向行为"一个 点"的研究转变为"一条线"(管理者→下属)的研 究。实证结果表明,管理者变革担当行为的下行 传递效应显著。由此可见,通过对管理者变革导 向行为的聚焦,本研究为变革导向行为的理论和 研究开辟了新的探索方向,同时也是对涓滴模式 下领导效应研究的有益补充。^{[17][18][19][22][23][24]}

其次 现有研究在考察变革导向行为发生机制 时多采用社会交换、社会认同等理论^{[14][41]},本研究 则以社会学习理论为框架 提出了管理者行为首先 会促使下属产生一定的认知反应,进而决定下属的 学习程度 最终影响下属行为的社会学习过程。具 体而言,管理者的榜样示范使下属对变革担当行为 形成了高奖励预期和低风险知觉的认知反应,从而 激发了学习动机,促进了下属变革担当行为的展 现。研究结果证实了奖励预期和风险知觉的双重 中介路径,为变革导向行为(尤其是变革担当行为) 的发生机制问题提供了新的认识视角,即通过社会 学习而促进此种行为表现。

最后,以往研究主要从组织支持氛围、权力距 离倾向、变革责任知觉等角度探讨变革担当行为 发生的边界条件。^{[7][42][43]}本研究则展示了一个以 下属变革担当效能信念为调节变量的被调节中介 模型,进一步证明了管理者行为的下行传递效应 是与下属的行为效能信念的高低息息相关的。本 研究发现下属变革担当效能信念是管理者变革担 当经由奖励预期作用于下属变革担当的重要边界 条件,且调节作用主要发生在中介链条的第二阶 段。研究结论佐证了行为动机和行为能力是影响 个体学习与模仿特定行为的两类重要因素的理论 观点^[21] ,更为系统全面的剖析了奖励预期和效能 信念的综合作用过程。

(三)管理启示

现阶段 变革和创新已成为全球范围内各企 业的共同诉求,处在转型升级关键期的中国企业, 要想取得新发展和获得竞争优势,变革势在必行。 首先,管理者应为下属树立学习榜样,身体力行地 实施变革举措,为企业组织营造全员变革和创新 的文化氛围提供重要推动力。其次,管理者可以 通过提升下属对变革担当行为的奖励预期,同时 降低其风险知觉来激发下属变革担当的行为动 机。组织一方面要重视员工贡献,加大对变革等 常规工作之外行为的奖励力度,通过物质报酬或 晋升机会等正向强化员工的变革担当行为;另一 方面 组织应为员工提供相对充足的资源 通过创 设各种支持性条件和环境,将变革的理念渗入企 业文化中 增强员工变革担当的价值感知 从而做 出变革担当行为。最后,管理者应意识到下属效 能信念是保证管理者变革担当通过奖励预期促进 下属变革担当行为的重要条件。组织可以通过肯 定员工的变革行为、宣传成功的变革案例等方式 来提升他们参与变革担当活动的自信心,并开展 一定的培训和项目开发,通过提高员工的行为技 能提升行为效能。另外,管理者的组织支持、适当 授权,也有助于消除下属从事挑战性工作的顾虑 与担忧,促使变革担当效能信念逐渐强化与内 在化。

(四)研究不足与展望

尽管本研究探讨了管理者变革担当影响下属 变革担当的中介机制和边界条件,也取得了一定 的研究成果,但仍存在着一些局限性,主要有以下 方面:第一,本研究采用多水平横截面的研究设 计,虽然能够观察层次因素带来的变异效果,却较 难考察因时间变化而出现的系统变异,未来研究 可以尝试在多水平设计的基础上增加时间维度的 考量,同时结合情景实验方法,能在一定程度上提 高本研究结论的准确程度和外部效度。第二,本 研究样本主要来自苏南地区,研究结果是否适用 其他地区还需要进一步检验,后续研究可以针对 更广泛的地域进行调研来提高研究结果的外部效 度。第三,在研究框架设计方面,本研究仅关注了 中介变量与结果变量之间关系的权变因素。显 然,下属是否模仿管理者行为以及模仿的程度,会 受到被模仿者地位、特征或双方亲疏关系的影响。 今后的研究可以进一步探索自变量管理者变革担 当与中介变量之间的权变因素,如管理者地位,下 属权力距离倾向,领导一成员交换关系,或者具有 中国文化特色的上下属关系(guanxi)等,以帮助我 们更为透彻地理解中国文化背景下管理者变革担 当激发下属变革担当的过程本质。

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The Conflict of the Rights Between Doctors and Patients in the Application of Electronic Medical Records and Its Legal Regulation

GAO Xue-juan

Abstract: The rights involved in electronic medical records in big data era are related to the coordination of doctor-patient rights. The abundant and varied types of information of electronic medical records have produced diversified "bundles of rights" and the corresponding subjects of rights , which inevitably lead to conflicts of rights in application. The current law regulating the application of electronic medical records has stipulated the patients' rights to personal information , security and reproduction and the doctors' rights to management , sharing , reproduction , modification and scientific research and other items. However , the ownership of electronic medical records is not defined. Moreover , the rights of doctors are most–ly positive and the rights of patients are mostly negative , between which there is an imbalance. Based on this fact , through the legally regulating approaches , such as incorporating patients' disease information into their personal information , defining the rules and regulations for utilizing the information of patients' medical records , vesting patients with the right to carry data so as to guarantee patients' rights to bounded and reasonable information self-determination , transform the pre-vious practice of passive defense and enable patients to take an active part in the sharing mechanism of electronic medical records , which is to restrict and safeguard the derivative rights of information for doctors on the basis of preserving patients' rights to information nature.

Key words: electronic medical records; conflict of rights; legal regulation

The Trickle-Down Effect of Managers' Reform Accountability in Business Organizations: Multilevel Moderated Mediator Model

DAI Yun TIAN Xiao-ming LI Rui

Abstract: Based on social learning theory, this paper has established a trickle-down model with the data from 315 pairs of employees and their immediate supervisors on their reform accountability, endeavoring to examine the mediator role of reward expectation and risk perception and the moderator role of the efficacy belief for reform accountability. The data analysis results with multilevel structural equation model have shown that managers' reform accountability is obviously and positively related to employees' reform accountability. Reward expectation and risk perception are the full mediator between managers' reform accountability and that of employees. The efficacy belief for reform accountability not only positively moderates the relationship between reward expectation and employees' reform accountability of their subordinates the indirect effect in which the managers' reform accountability influences the reform accountability of their subordinates via reward expectation. However, efficacy belief for reform accountability does not play an apparent role in mediating the relationship between risk perception and the reform accountability of subordinates.

Key words: reform accountability; reward expectation; risk perception; efficacy belief for reform accountability

The Iteration Mechanism of Language and Its Role in Referential System MA Qing-hua HAN Xiao

Abstract: Based on relevant ontological research results of linguistics, this paper proposes a linguistic iteration system composed of multiple iteration types and their distributions. Afterwards, it focuses on the analysis of the characteristics and laws of the iteration mechanism in the referential iteration model and achieves a series of new discoveries, such as the multidimensional iteration, the improvement and decline of the referential capacity after multiple-wave application of multidimensional iteration. The conclusion proves that iteration is an important operation mechanism with profound significance in complex linguistic systems, which shows unique capacity for discovery and explanation in in-depth study of languages.

Key words: iteration mechanism; iteration system; referential iteration model; multidimensional iteration; the wave of multidimensional iteration; capacity improvement; capacity decline

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失地农民再就业培训参与决策机制的探讨

——基于扎根理论的质性分析

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摘 要:为了提高失地农民再就业培训参与率,开展了一项基于扎根理论的质性分析研究,提出了有关 "失地农民再就业培训参与决策机制"的实质理论,并得出两个主要结论:(1)失地农民的再就业培训参与决 策包含有"特征感知"和"价值评价"这两个基本过程。(2)结合前景理论,可认为"特征感知"过程与"编辑" 阶段相对应,主要涉及对"机构实力""师资力量""项目质量"这三个方面的特征感知;而"价值评价"过程 与"评价"阶段相对应,主要涉及对"就业素质提升""能力证书获取""就业目标实现"这三个选项结果的前 景价值评价,以及对"总体前景价值"的评价。与前景理论结合起来,该实质理论有助于解释"失地农民再就 业培训参与决策行为",促进对"再就业培训系统"运行机制及当前"招生效果"不佳现象的理解,拟定出更 多有针对性的对策以提高失地农民再就业培训参与率。

关键词: 失地农民; 再就业培训; 决策机制; 扎根理论; NVivo软件

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一、引言

习近平总书记在党的十九大报告中指出,"就 业是最大的民生"。这充分说明了就业问题的重 要性。在中国目前面临的各种就业问题中,失地 农民的再就业问题最为突出,对就业管理与服务 部门而言,其解决也最具挑战性。

(一)问题背景与研究意义

目前,中国正处在高速城镇化的进程中,成 千上万的农民因城镇化失去了土地而成为失地农

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民。据估计,到2020年,我国失地农民预计将超过1个亿。^[1]对于这部分人而言,尽管在土地被征用的过程中会获得一定额度的安置补偿款,但是"仅仅依靠安置补偿款无法保障失地农民的可持续生计"^[2]。要解决长远生计,对于那些尚在劳动年龄段的失地农民而言,最好要能以非农就业方式重新就业。

然而,由于受教育程度、非农就业技能和综 合素质均较低,失地农民在就业市场中常常处于 劣势,缺乏就业竞争力[3],以致很难充分实现再 就业目标。邵爱国和韦洪涛[4]的调查研究也显示, 年龄大、文化程度低、能力不足,是阻碍该群体再 就业的最主要因素。这种不是因为劳动力市场没 有充足的就业岗位,而是因为受教育(文化)程度、 非农就业技能(能力)和综合素质较低而导致的就 业难问题,实际上是一种典型的结构性就业矛盾。 而吴婧^[5]的调查研究进一步说明,"结构性失业 严重"是当前失地农民面临的主要困境之一。开 展再就业培训是目前我国安置失业人员、转岗人 员的主要方法,通过培训可帮助他们"建立符合 社会发展需要的职业知识技能与良好的职业素养 心态"[6],从而最终实现再就业的目标。而在各种 职业技能培训中,失地农民是最重要的群体之一。 通常而言,为促进失地农民充分再就业而开展的 职业技能培训,被称为失地农民再就业培训。此 类培训有助于缓解失地农民的结构性就业矛盾。

然而,在开展失地农民再就业培训工作中, 有很多因素可能会阻碍再就业培训工作的有效 开展而成为瓶颈因素。"参与比率低"^[7]或"参与 度不高"^[5]就是其中之一。邵爱国、韦洪涛和杜 丽君^[8]探讨了长效再就业培训系统。根据他们的 观点,"招生效果"好,即招募到足够多的学员, 是确保系统有效运行的重要前提。"参与比率低" 或"参与度不高"都意味着"招生效果"不佳。而 这些情况,都可能会导致针对失地农民的再就业 培训系统无法可持续运行。

由此可见,努力提高失地农民再就业培训的 "参与比率",对于建构长效再就业培训系统、缓 解失地农民结构性失业问题、落实"就业是最大 民生"的治国理念而言,都具有重要的实践意义。

(二)理论基础与问题提出

"参与比率低",在某种意义上反映的是目前 所开发的再就业培训项目缺乏足够的价值,以致 无法对失地农民产生很大的吸引力,使得只有少数人能够做出"参与"再就业培训的选择。尽管这 类培训的学费都有政府专项资金补助,无须个人 支付任何费用,但受各种因素的影响,选择"参 与"再就业培训这一选项,对于每个个体而言,结 果的意义、价值及实现的可能性都是不一样的。

首先,选项结果的意义及价值往往会因人而 异。在价值哲学研究领域中,主观价值论流派对 价值的基本观点是:价值由作为主体的"人"本 身所赋予,取决于人本身的欲望、需求、情感、兴 趣等主观元素。^[9]然而,每个人在这些主观元素 上都有着很大的差异。因此,对于失地农民而言, "参与"再就业培训这一选项的价值有多高,以及 相对于"不参与"再就业培训这一选项是否更有 价值,都会因人而异。

其次,每个人对"选项结果实现可能性"的主观感受也是不一样的,即个体对结果发生的主观 概率判定也会因人而异。一些研究显示,个体的 工作记忆能力^[10]、情感^[11]等因素都会影响到自身 对决策结果的主观概率判定。由此可见,对于失 地农民而言,是否"参与"再就业培训是一项典型 的风险决策,而选择"参与"再就业培训这一选项, 对于每个人而言,"值不值得"往往会因人而异。

在风险决策领域中,解释个体决策行为的理论有很多,其中前景理论是最常用的理论之一。前景理论是Kahneman和Tversky^[12]首先提出的。该理论将风险决策过程分为编辑和评价两个阶段。在编辑阶段,决策者会"对不同的可能性结果进行初步分析,建立适当的参考水平(参照点),确定概率值,得出简化的结果";在评价阶段,决策者"对编辑得到的简化结果进行评估,选择前景(价)值最高的决策"^[13]。

Kahneman和Tversky改变了传统理论评估总效应的做法,转而衡量一个前景的总价值V,该价值主要是通过价值函数 $v(\cdot)$ 和决策权重函数 $\pi(\cdot)$ 的结合来决定的。^[14]价值函数反映了结果的主观价值,决策权重函数表示与该结果概率P相对应的决策权重,它和客观概率P有着本质的区别,它反映了P对整个前景值的影响力,"是决策者根据事件结果出现的概率(p)做出的某种主观判断"^[15]。这意味着决策者在进行风险决策时,至少会受到两个方面的影响:一是决策者对结果出现的

主观概率判定的影响。

前景理论自提出以来,被广泛用来解释各种 类型的决策行为。但还未有人应用该理论来分析 失地农民是否参与再就业培训的决策机制(以下 简称"失地农民再就业培训决策机制")。本研究 认为,如果应用前景理论来解释失地农民再就业 培训参与决策机制,那么可以推出以下三个假 设:(1)失地农民进行再就业培训参与决策机制 中包含有编辑和评价两个过程;(2)失地农民进 行再就业培训参与决策机制中包含有主观价值判 断和主观概率判断;(3)失地农民选择"参与"再 就业培训,是因为该选项对应的前景价值大于"不 参与"再就业培训这一选项对应的前景价值。

而基于这三个假设,可衍生出如下一系列问 题:如果失地农民感知到"参与"再就业培训这 一选项的前景价值要高于"不参与"选项的前景 价值,那么这样的再就业培训具有什么样的特 征?透过这些特征的分析,能否确定出失地农民 在进行是否参与再就业培训决策时的主要认知内 容?这些认知内容,是否也是分布在不同的决策 过程或阶段中? 而根据这些认知内容, 能否分析 出有哪些可能会影响失地农民对"参与"再就业 培训这一选项结果的主观价值感受和主观概率判 定的因素? 如果有的话, 可分为哪些方面? 而对 于那些不同方面因素的特征认知,相互之间有无 关系?如果有关系,其作用机制是什么?本研究 认为, 厘清这些问题, 将有助于描述失地农民再 就业培训参与决策的机制,而利用该机制,可拟 定出更有效的干预措施,以提高失地农民再就业 培训的"参与比率"。本研究拟围绕这些问题进行 探索,以期对失地农民再就业培训参与决策机制 能有更深刻的认识。

二、研究方法

为了实现上述研究目的,本研究拟采用基于 扎根理论的研究范式。扎根理论最早由 Glaser 和 Strauss^[16]提出。该理论是一种对定性资料进行分 析以建构理论的研究方法,其首要任务就是建立 "实质"理论^[17]。这是一种自下而上建立理论的 方法,即在系统收集资料的基础上,寻找反映社 会现象的核心概念,然后通过在这些概念之间建 立起联系而形成理论。^[17]本研究期待,经过扎根 理论研究的探索,最终能概括出有关"失地农民 再就业培训参与决策机制"的理论模型,以更好 地理解当前失地农民再就业培训中"参与比率低" 的现象,寻求到更有针对性的应对策略。

(一)研究对象

对于一项扎根理论研究而言,获取与研究主题相关的经验事实是开展研究的第一步。为了探索"失地农民再就业培训参与决策机制"的理论模型,本研究拟以长三角地区的失地农民为研究对象,并以该群体对能促使他们做出"报名参与" 决定的再就业培训特征的"看法"为质性分析内容,积极探究失地农民再就业培训参与决策机制。

(二)研究工具

本研究中资料搜集所使用的工具是自编问 卷。问卷包括三大部分:一是人口变量,具体包 括性别、学历、出生时的户籍、当前户籍和年龄; 二是有关家庭的土地情况,具体包括:"近30年 来家中是否有过被征地的情况"以及"当前家庭 人均耕地状况"; 三是一道开放式问题, 内容是: "为了促进就业,很多地方政府会提供免费的再 就业培训,请问:政府提供一个什么样的培训, 才会让您作出'报名参与'的决定"。开放式问题 经常被调查研究者用来了解公众意见。^[18]Hickey 和Kipping^[19]认为,可利用开放式问题搜集资料 并进行编码。Arnold, Heller和Kramer^[20]的研究 就使用了开放式问题来搜集被试的反应,以作为 扎根理论研究的分析资料。本研究认为,利用上 述开放式问题可以搜集到失地农民对能促使他们 做出"报名参与"决定的再就业培训的特征的"看 法"。基于这些"看法"构成的描述性文本,可作 为扎根理论研究的分析资料。

(三)资料采集及被试特征

课题组在长三角地区的苏州、无锡、杭州和 上海四地的劳动力市场发放了3400份调查问卷。 利用"出生时的户籍"(城市/农村)、"近30年来 家中是否有过被征地的情况"(有过/未曾有过) 这两道题遴选出失地农民(这两道题是参与上述 开放式问题作答的前置条件),在剔除掉无效作 答样本之后,最终获得有效样本513份。这些样 本的被试,均具有出生时为"农村"户籍、近30年 来家中"有过"被征地情况的特征。鉴于这些被试 都在劳动力市场中求职,可将其视作"失业或无 业状态"中的失地农民。被试的人口学特征如表1 所示。

变量	类别	人数(N)	百分比(%)
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~	男	263	51.3
作生力中	女	250	48.7
	小学及以下	12	2.3
	初中	191	37.2
学历	中专、高中等	253	49.3
	大专	45	8.7
	本科及以上	12	2.5
业益白粹	城镇户籍	347	67.6
ヨ則广 積	农村户籍	166	32.4
	30岁以下	405	78.9
年龄段	30~39岁	88	17.2
	40岁及以上	20	3.9
	没有土地	128	25.0
家庭人均耕地	少于0.3亩	305	59.5
	大于 0.3 亩	80	15.5

表1 被试特征(N=513)

(四)资料整理与分析

根据 Strauss 和 Corbin 的观点,扎根理论利 用三个阶段的编码方式用以裂解原始资料、概 念化,并重新产生新的形式,此三个阶段编码包 括开放编码、主轴编码与选择编码。^[21]三个阶 段编码通常也被称为三级编码。为了更有效率 地进行编码分析,本研究借助了质性分析软件  $NVivo11.0_{\,\circ}$ 

#### 三、研究结果

(一)三级编码

1. 开放编码

开放编码是扎根理论研究的第一步。在 NVivo软件中,将原始资料编码成自由节点的步 骤属于开放编码阶段,"目的在形成初步的资料 范畴"[22]。本研究首先对开放式问题的内容文本 进行开放编码,结果得到了676个参考点(即质 性资料中被编码的内容),并归纳出36个自由节 点。依据自由节点所包含的参考点数由大到小排 序,可得表2所示结果。在该表中,同时还计算出 了每个节点对应的百分比及累计百分比。根据帕 累托图分析法[23],累计百分比在0~80%之间的选 项内容,可称为"主要因素"(也被称为A类)。据 此,可确定出前11个自由节点是主要因素,即A 类节点。这些节点的名称及其对应的典型参考点 如表2所述。对节点的命名主要基于含括的参考 点所具有的共同特征。以"有用的"这一自由节点 为例,该节点中的典型参考点有"实用的""有用 的""实用性强的""有效果的""有意义的""有帮 助的"等。显而易见,这些参考点所描述的内容 都是被试针对再就业培训"有用性"做出的评价。 为此,本研究将该节点命名为"有用的"。

序号	自由节点	参考 点数	百分比 (%)	累计百分比 (%)	典型参考点
1	有用的	94	13.91	13.91	实用的;有用的;实用性强的;有效果的;有意义的;有帮助的
2	有技能技术含量的	91	13.46	27.37	技能;有技术含量的;动手操作的
3	可促进就业的	60	8.88	36.24	培训后能帮助就业;能提供就业机会;可获得面试 机会;有助于面试;有助于快速找到工作的;有助 于找到新工作;快速找到工作
4	有针对性的	52	7.69	43.93	有针对性的;对口的;扬长避短的
5	可应用于实践的	47	6.95	50.89	有实践性的;理论结合实践的
6	具有专业性的	44	6.51	57.40	专业的;专业性强的
7	特定领域的	41	6.07	63.46	电脑方面的;关于挖掘机的
8	专业能力强的	39	5.77	69.23	专业的老师;有能力的;擅言谈;讲的生动;活泼 生趣;课堂轻松愉快;讲解清楚的;讲解到位;采 用案例教学的;案例教学为主的
9	可学到技能技术的	27	3.99	73.22	可学到技能技术的;掌握一些技能

表2 开放编码所得自由节点及典型参考点

					:	续表
序号	自由节点	参考 点数	百分比 (%)	累计百分比 (%)	典型参考点	
10	易懂易学的	25	3.70	76.92	简单;易懂;易学	
11	有广泛市场需要的	17	2.51	79.44	符合社会需求的;跟上社会发展的	
12	符合学员兴趣的	17	2.51	81.95	感兴趣的;个人爱好的	
13	能找到好工作的	16	2.37	84.32	能帮我找到好工作;能找到高薪工作	
14	个人品质好的	14	2.07	86.39	负责;细心;自信;幽默;用心	
15	有发展前景的	13	1.92	88.31	有前景;有发展前途;有发展空间	
16	可学到知识的	10	1.48	89.79	可学到知识的	
17	学费较低的	9	1.33	91.12	不要钱;免费的;花钱少	
18	声誉好的	8	1.18	92.31	专家;有名气的;有权威;口碑好	
19	用时短的	8	1.18	93.49	快速提高; 高效率的; 培训时间短	
20	丰富全面的	7	1.04	94.53	内容丰富; 内容全面; 信息全面	
21	务实可行的	7	1.04	95.56	务实的;实事求是;现实可行的	
22	目标明确的	6	0.89	96.45	目标明确的;有一定目标计划的	
23	影响长远的	3	0.44	96.89	影响长远的;有持久性的影响	
24	正规的	3	0.44	97.34	正规的;有资质的	
25	新颖的	3	0.44	97.78	内容新颖;有创意的;有开拓思维	
26	可强化就业素质的	2	0.30	98.08	可强化就业素质;真正提升就业素质	
27	可获得学历证书的	2	0.30	98.37	能拿到文凭;可提高学历	
28	可获得考试合格证书的	2	0.30	98.67	培训后能拿到证书;能拿到合格证书	
29	学员需要的	2	0.30	98.96	学员需要的	
30	有助于自主创业的	1	0.15	99.11	有助于创业的	
31	可获得技能等级证书的	1	0.15	99.26	可以发技能证书	
32	可获得职业资格证书的	1	0.15	99.41	就业资格证书	
33	组织管理能力强的	1	0.15	99.56	机构的组织管理能力较强	
34	有特色的	1	0.15	99.70	培训机构有特色	
35	有一定规模的	1	0.15	99.85	培训机构有一定规模的	
36	诚信的	1	0.15	100.00	机构富有诚信的	
	合计	676	100.00			

2. 主轴编码

在NVivo软件中, 主轴编码就是利用树状节 点功能对自由节点进一步归纳, 其"目的在于将 开放(性)编码中被分割的资料进行类聚, 划分 出更高层级的主要范畴(即形成概念范畴), 并 建立范畴之间的关联, 形成对现象更为精确的解 释"^[22]。经过主轴编码, 36个自由节点可被归纳 为"总体前景价值""就业目标实现""就业素质提 升""能力证书获取""师资力量""机构实力""项 目质量"这七个概念范畴。如表3所示,"项目质 量"(389)、"总体前景价值"(97)和"就业目标实现"(77)这三个概念范畴上分布的参考点最多,合计563个,累计占到总体的百分比为83.28%。可见,这三个概念范畴最为核心。基于概念范畴所包含的自由节点的内涵,本研究对每个概念范畴做出了如下解释:

(1)"总体前景价值"包含"有用的"和"影响 长远的"这两个自由节点,指的是个体在"再就业 培训参与决策"之前对培训项目形成的一种综合 的前景价值(预期价值)判断。

太♂ 二级编码的结果						
选择编码	主轴编码	参考点数	百分比	开放编码		
(核心范畴)	(概念范畴)	(N)	(%)	(自由节点)		
	总体前景价值	97	14.35	有用的; 影响长远的		
	就业目标实现	77	11.39	可促进就业的;能找到好工作的;有助于自主创业的		
价值评价	就业素质提升	39	5.77	可学到技能技术的;可学到知识的;可强化就业素质的		
	能力证书获取	6	0.89	可获得学历证书的;可获得考试合格证书的;可获得技能等级证书的;可获得职业资格证书的		
	小计	219	32.40			
	师资力量	61	9.02	专业能力强的;个人品质好的;声誉好的		
	机构实力	7	1.04	正规的;组织管理能力强的;有特色的;有一定规模的;诚信的		
特征感知	项目质量	389	57.54	有技能技术含量的;有针对性的;可应用于实践的;具有专业性的;特定领域的;易懂易学的;有广泛市场需要的;符合学员兴趣的;有发展前景的;学费较低的;用时短的;丰富全面的;务实可行的;目标明确的;新颖的;学员需要的		
	小计	457	67.60			
合计		676	100.00			

(2)"就业目标实现"包含"可促进就业的""能 找到好工作的""有助于自主创业的"这三个自由 节点,指的是个体在"再就业培训参与决策"之前 对"培训项目在促进就业目标实现"方面形成的 前景价值判断。

(3)"就业素质提升"包含"可学到技能技术 的""可学到知识的""可强化就业素质的"这三个 自由节点,指的是个体在"再就业培训参与决策" 前对"培训项目在促进就业素质提升"方面形成 的前景价值判断。

(4)"能力证书获取"包含"可获得学历证书 的""可获得考试合格证书的""可获得技能等级 证书的""可获得职业资格证书的"这四个自由节 点,指的是个体在"再就业培训参与决策"前对"培 训项目在促进各种(就业)能力证书获取"方面形 成的前景价值判断。

(5)"师资力量"包含"专业能力强的""个人 品质好的""声誉好的"这三个自由节点,指的是 个体在"培训参与决策"前对培训"师资力量"方 面的特征感知。这些自由节点都是衡量师资力量 的重要指标,即当一个再就业培训项目具备更多 这些节点所描述的特征时,个体更倾向于认为项 目依托有雄厚的师资力量。

(6)"机构实力"包含"正规的""组织管理能 力强的""有特色的""有一定规模的""诚信的" 这五个自由节点,指的是个体在"再就业培训参 与决策"前对"培训机构开展培训业务的能力"的 特征感知。这些自由节点反映的都是培训机构的 实力,即当一个再就业培训项目具备更多这些节 点所描述的特征时,个体更倾向于认为项目依托 的培训机构有着强大的实力。

(7)"项目质量"包含16个自由节点(具体名 称如表3所述),这些自由节点反映的都是高质量 培训项目的特征,也就是说,当一个再就业培训 项目具备更多这些节点所描述的特征时,个体更 倾向于认为项目是"有质量的"。其中,有七个自 由节点属于36个自由节点中的A类节点(即主要 因素),分别为"有技能技术含量的""有针对性的" "可应用于实践的""具有专业性的""特定领域的" "易懂易学的""有广泛市场需要的"。

3. 选择编码

选择编码是扎根理论的第三级编码,其目的 在于进一步概括和归纳已发现的概念范畴,以形 成核心范畴。经过选择编码,七个概念范畴最终可 概括为"价值评价"和"特征感知"这两个核心范畴。

其中,"价值评价"包含"就业素质提升""能 力证书获取""就业目标实现""总体前景价值"这 四个概念范畴。之所以将其概括为"价值评价", 是因为它们反映的都是"参加再就业培训之后, 可能会得到的收益",其中"就业素质提升""能力

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证书获取""就业目标实现"是较为具体的三项结 果上的收益。而"总体前景价值",则是基于全部 结果上的收益作出的综合性评价。毫无疑问,有 关收益的评价,实质就是价值评价。

而"特征感知"包含"机构实力""师资力量" "项目质量"这三个概念范畴。之所以将其概括为 "特征感知",是因为它们反映的都是个体对再就 业培训项目及相关要素(如,培训机构及师资)的 特征感知。基于这些感知,可获得对"项目质量" "机构实力""师资力量"的评价信息。

(二)关系节点分析与模型建构

在经过自由节点及树状节点分析之后,还要处理这些节点之间的关系。郭玉霞^[21]认为,"如 果我们将自由节点、树状节点视为第一层次的编码,那么关系节点就是第二层次的编码"。树状节 点"可以表现质性研究概念间的相互关系"^[24], 但"只能用来表示项目上下的阶层关系,很难完 整描述研究概念间的关联性"^[21]。为此,NVivo提 供了关系和模型来协助。在NVivo中,"关系是一 种特殊的节点,它可藉由线条符号及关系形态来 说明两项之间的关联性"^[21]。而"模型通常由形 状与连接线所构成"^[24],有助于更加形象地呈现 项(概念或变量)间的相互关系。

基于七个概念范畴之间的关系分析,本研究 建构了如图1所示的理论模型,提出了"失地农 民再就业培训参与决策机制"。在该机制模型中, 合计包含14个关系假设:(1)机构实力→师资力 量;(2)师资力量→机构实力;(3)机构实力→ 项目质量;(4)师资力量→项目质量;(5)总体 前景价值→培训参与决策;(6)就业素质提升→ 总体前景价值;(7)就业目标实现→总体前景价 值;(8)能力证书获取→总体前景价值;(9)就 业素质提升→能力证书获取;(10)就业素质提 升→就业目标实现;(11)能力证书获取→就业 目标实现;(12)项目质量→就业素质提升;(13) 机构实力→就业素质提升;(14)师资力量→就 业素质提升。在这14个关系假设中,"→"代表前 者对后者具有直接的影响力。



图1 失地农民再就业培训参与决策机制

在这14个关系假设中,关系假设1—4反映的是"特征感知"这一核心范畴下的三个概念范 畴之间的相互关系。这四个关系假设描述的是: 个体对"机构实力"和"师资力量"形成的评价越 积极,对"项目质量"形成的评价也越趋向于积极;个体对"机构实力"和"师资力量"形成的评价也越趋向于积极;个体对"机构实力"和"师资力量"形成的评价越积极,对"师资力量"形成的评价也会越积极,反之 亦然。通常情况下,人们会认为:那些"机构实力" 强的培训机构,能够吸引到更多优秀教师,而这 将使得"师资力量"更为雄厚;培训机构里有足 够多优秀教师("师资力量"雄厚),会令学员产生 培训机构很强大("机构实力"强)的感觉,因为 只有实力强大的机构才能请得起最好的教师;而 "机构实力"强大、"师资力量"雄厚的培训机构, 更有可能提供出优质的培训项目或培训服务("项 目质量"高)。

关系假设5认为,失地农民最终能否会做出 "报名参与"再就业培训的选择,主要是由该选项 对应的"总体前景价值"决定的。这一关系假设是 根据前景理论的观点推论出来的。本研究认为, 失地农民在进行"是否参与"再就业培训的决策 时,会对"参与"和"不参与"这两个选项分别做 出"前景价值"的判断。根据判断结果,个体最终 会选择"前景价值"相对较大的选项。

关系假设6—11反映的是"价值评价"这一核 心范畴下"总体前景价值""就业素质提升""能力 证书获取"和"就业目标实现"这四个概念范畴之 间的相互关系。本研究认为:"就业素质提升""能 力证书获取""就业目标实现"是个体做出了"参 与"再就业培训选择之后可能会产生的三项主要 结果: 失地农民除了要对"总体前景价值"进行 评价之外,还会对这三项主要结果进行前景价值 评价:对这些具体结果的前景价值评价,是失地 农民形成对"参与"再就业培训洗项"总体前景价 值"评价的基础。也就是说,失地农民对上述三 项结果的前景价值评价越大,对"总体前景价值" 的评价也就越大,而这正是关系假设6-8的观 点。此外,本研究还认为,"就业素质提升""能力 证书获取""就业目标实现"这三个概念范畴之间 也存在着一定的联系。鉴于"能力证书"是对"就 业素质提升"的一种证明,即有了显著的"就业素 质提升"才能得到相应的"能力证书"。为此,本研 究提出了关系假设9。鉴于"拥有能力证书"可反 映"就业素质"水平高低,而用人单位更倾向于选 择"就业素质"强的求职者,本研究认为"就业素 质"强并拥有相应"能力证书"的求职者更容易实 现"就业目标",而这正是关系假设10—11的观点。

而关系假设12—14反映的则是"项目质量" "机构实力""师资力量"这三个概念范畴,是如何 作用于"就业素质提升"这一概念范畴的。鉴于再 就业培训项目的目的是"通过向失地农民提供再 就业培训服务,以提高就业素质,并实现再就业 的目标",可认为"再就业培训服务"是提高失地 人员就业素质的手段, 而就业素质提升的幅度, 就是再就业培训服务最直接的效果, 而影响"再 就业培训服务"效果的,培训项目自身的质量(即 "项目质量")必然是主要的因素之一。因此,本研 究认为,失地农民对可影响到"项目质量"高低的 那些特征的感知,必然会影响到自身对"就业素 质提升"这一结果的前景价值评价,而这正是关 系假设12的观点。此外,失地农民对"机构实力" 和"师资力量"的特征感知,也有助于提高自身对 "就业素质提升"这一结果前景价值大小的评价。 通常情况下,如果失地农民经过信息搜集与分析 能够感受到"机构实力"强大、"师资力量"很雄厚, 那么就更有可能形成"如果选择'参与'再就业培

训这一选项,'就业素质提升'这一结果就更有可 能实现"这一主观感受。这意味着,个体对"机构 实力"和"师资力量"有积极的特征感知,将会促 进自身对"就业素质提升"这一结果实现主观概 率的评价。根据前景理论,主观概率越大,决策 权重就越大,相应的前景价值也会越大。而鉴于 "项目质量""机构实力""师资力量"隶属于"特 征感知"这一核心范畴,"就业素质提升"隶属于 "价值评价"这一核心范畴,本研究认为,关系假 设12—14所反映的,就是两个核心范畴之间的联 系机制。

#### 四、分析与讨论

作为扎根理论研究的结果,"失地农民再就 业培训参与决策机制"这一理论模型可被视为实 质理论。在该实质理论中,七个概念范畴可被归 纳为"特征感知"和"价值评价"这两大核心范畴。 从决策心理过程的角度,可将"特征感知"和"价 值评价"视为失地农民再就业培训参与决策的两 个基本过程。从内涵上讲,这两个过程与前景理 论有关风险决策中存在"编辑"和"评价"这两个 阶段的观点基本一致。即是说,在失地农民再就 业培训参与决策中,"特征感知"过程与"编辑" 阶段相对应,"价值评价"过程与"评价"阶段相 对应。本研究认为,上述实质理论,与前景理论 结合起来,可有效解释"失地农民再就业培训参 与决策行为"、促进对"再就业培训系统"运行机 制及当前"招生效果"不佳现象的理解。

(1)可有效解释"失地农民再就业培训参与 决策行为"

"前景理论"自提出以来, 被广泛用来解释各 类风险决策行为。但是, 在解释"失地农民再就 业培训参与决策行为"上, 单靠前景理论还不能 给予更为具体的解释。比如, 在"编辑"阶段, 究 竟编辑了哪些信息? 在"评价"阶段, 究竟评价了 哪些选项结果? 诸如此类问题, "前景理论"还不 能单独解释。而上述实质理论的提出, 可以深化 前景理论对这些问题的解释, 从而使得对"失地 农民再就业培训参与决策行为"的解决更为有效。

首先,可深化对"编辑"阶段的解释。在再就 业培训参与决策中,"编辑"阶段对应的是"特征 感知"这一过程。"特征感知"作为核心范畴包括 "项目质量""机构实力""师资力量"这三个概念 范畴。也就是说,在再就业培训参与决策中,"编 辑"阶段所涉及的信息,主要就是这三个方面的。 此外,个体对这三个方面的"信息"编辑,相互之 间也有着一定的联系——失地农民如果感知到 "机构实力"强大和"师资力量"雄厚,那么就更 倾向于认为"项目质量"高;而失地农民如果感 知到"机构实力"强大,也更倾向于认为"师资力 量"雄厚。反之,亦然。

其次,可深化对"评价"阶段的解释。在再 就业培训参与决策中,"评价"阶段对应的是"价 值评价"这一过程。"价值评价"作为核心范畴包 括"就业素质提升""能力证书获取""就业目标实 现""总体前景价值"这四个概念范畴。其中,"就 业素质提升""能力证书获取"和"就业目标实现" 代表的是个体选择"参与"再就业培训这一选项 可能会产生的三个潜在结果。本研究认为,失地 农民除了会进行"总体前景价值"评价之外,还会 针对这三个结果分别做出前景价值评价;对这三 个结果的前景价值评价越大,对"总体前景价值" 的评价也就越大。此外,对这三个结果的前景价 值评价相互之间也有一定联系——对"就业素质 提升"的前景价值评价越高,对"能力证书获取" 的前景价值评价也会越高:对"就业素质提升""能 力证书获取"的前景价值评价越高,对"就业目标 实现"的前景价值评价也会越高。

再次,还深化了对"评价"和"编辑"这两个 阶段联系机制的认识。本研究认为,失地农民对 "项目质量""机构实力""师资力量"的特征感知 越积极,对"就业素质提升"这一选项结果的前 景价值评价也会越高。鉴于"项目质量""机构实 力""师资力量"隶属于"编辑"阶段,而对"就业 素质提升"的前景价值评价隶属于"评价"阶段, 因此,失地农民对"项目质量""机构实力"和"师 资力量"的特征感知,同对"就业素质提升"这 一选项结果的前景价值评价之间的关系,所反映 的其实就是"评价"和"编辑"这两个阶段的联系 机制。

(2)可促进对"再就业培训系统"运行机制及 当前"招生效果"不佳现象的理解

"失地农民再就业培训参与决策机制"这一实 质理论的提出,在一定程度上支持了邵爱国、韦 洪涛和杜丽君^[8]对长效再就业培训系统的研究, 促进了我们对该系统运行机制的理解。邵爱国、 韦洪涛和杜丽君^[8]构建了一个包含多条反馈回路的"再就业培训系统因果反馈关系图",其中有一条反馈回路是:外部支持→政策保障→经费补贴 →培训力量→项目引力→招生效果→培训效果→ 外部支持。构成该回路的都是再就业培训系统的 子系统要素(以下简称"要素")。在该回路所包 含的关系中,其中有两个是:"培训力量"要素的 功效,会增强"项目引力"要素的功效;"项目引 力"要素的功效,会增强"招生效果"要素的功效。 但是,该研究仅从中观系统的层面阐述了这些要 素之间的关系,却未从微观个体的心理层面加以 解释。尤其是,有关"'项目引力'是如何产生的" "'培训力量'是如何增强'项目引力'的,而'项 目引力'又是如何增强'招生效果'的"等问题, 还需更进一步解释。

本研究认为,该研究中述及的"项目引力", 在一定意义上就是失地农民群体对培训项目"总 体前景价值"的感受;而"培训力量"则含括了本 研究中的"机构实力"与"师资力量"。根据本研 究建构的"失地农民再就业培训参与决策机制" 这一实质理论,如果失地农民感知到"机构实力" 和"师资力量"(亦即"培训力量")较弱,并感知 到"项目质量"较低,那么对项目的"总体前景价 值"的评价必然会小——而再就业培训项目也会 因此而缺乏"项目引力",难以吸引到更多失地 农民报名参加,以致出现较低水平的"培训参与 率"——"招生效果"也自然会不佳。目前,在失 地农民再就业培训实践中,时常会出现"培训参 与率低"或"招生效果"不佳的现象,其本质的原 因,还是目前可供选择的再就业培训项目的"总 体前景价值"不够大。

而基于本研究构建的这一实质理论,可以从 微观的个体心理层面,有效解释"培训力量"(包 括"机构实力"和"师资力量")、"项目质量"、项 目的"总体前景价值"("项目引力")和"招生效果" ("培训参与率")之间的联系机制,在一定程度上 促进了我们对"再就业培训系统"运行机制及当 前"招生效果"不佳现象的理解。

#### 五、建议

要提高失地农民再就业培训参与率,改善目 前再就业培训的招生效果,关键还是要提升再就 业培训项目的前景价值。基于本研究构建的实质 理论,结合前景理论,本研究围绕再就业培训项 目前景价值的提高,拟定了两类建议:

(1)提高培训项目质量,建立合理参照点,努力提高价值函数值

根据前景理论,决策者会在编辑阶段"对不同 的可能性结果进行初步分析,建立适当的参考水 平(参照点),确定概率值,得出简化的结果"[13]。 当个体感知到洗项结果的价值高于参照点,就会 产生"收益"的感受;反之,就会产生"损失"的 感受。可见,最终形成是"收益"还是"损失"的 价值感受取决于两方面的因素,一是洗项结果本 身的价值,二是参照点的水平。首先,提高项目 本身的价值,有助于形成是"收益"的感受。本研 究认为,影响失地农民对选项结果的价值感受, 主要是"项目质量"。确保培训项目具有更多"项 目质量"概念范畴下那些自由节点所包含的特征 (如"有技能技术含量的""有针对性的"等),将 有助于提高失地农民对参与再就业培训这一选项 的价值感受。其次,降低参照点水平,也有助于 形成是"收益"的感受。通常情况下,参照点可分 现状参照点和非现状参照点这两类。[25]前者是指 "个体以目前所处的现实情况为参照点(如,当前 的财富水平);而后者是指"在无客观现状参照 的情况下,个体通常会以目标绩效、期望等对未 来的知觉作为参照点"。本研究认为,可采取一些 适当措施,如提供一些引导性培训、就业咨询与 指导等服务,来帮助失地农民进行科学的目标设 置与期望管理,建立出合理的参照点,以做出更 加理性的价值判断与行为选择。

(2)加强培训机构的实力建设和师资建设, 注重"关键信息"的有效传播,努力提高概率函数值

提高概率函数的值,就是要努力让失地农民 相信,"当自己做出了'参与'再就业培训这一决 策之后,自己预期的结果有较大可能的实现"。结 合上述实质理论,本研究提出如下两点建议:一 要努力加强培训机构的实力建设和师资建设。培 训机构实力强大、师资力量雄厚,意味着培训的 计划实施和品质可以得到更多的保障,这将有助 于失地农民形成"预期结果"更有可能实现的信 念。二要注重"关键信息"的有效传播。建议多搜 集、多总结、多宣传一些成功个案,尤其是那些 有关失地农民经过再就业培训成功促进了"就业 素质提升""能力证书获取""就业目标实现"的案 例。积极正面的宣传,将有助于增强失地农民对 预期结果实现可能性的感受。

#### 六、小结

本研究基于扎根理论的质性分析,提出了一 个有关"失地农民再就业培训参与决策机制"的 实质理论,并得出两个主要结论:(1)失地农民 的再就业培训参与决策包含有"特征感知"和"价 值评价"这两个基本过程。(2)结合前景理论,可 认为"特征感知"过程与"编辑"阶段相对应,主 要涉及对"机构实力""师资力量""项目质量"这 三个方面的特征感知;而"价值评价"过程与"评 价"阶段相对应,主要涉及对"就业素质提升""能 力证书获取""就业目标实现"这三个选项结果的 前景价值评价,以及对"总体前景价值"的评价。 与前景理论结合起来,该实质理论有助于解释"失 地农民再就业培训参与决策行为",促进对"再就 业培训系统"运行机制及当前"招生效果"不佳现 象的理解, 拟定出更多有针对性的对策以提高"失 地农民再就业培训参与率"。

需要认识到的是,受限于方法论,本研究所 建构的"失地农民再就业培训参与决策机制"这 一"实质理论",虽然有助于揭示再就业培训参与 决策中各个变量(概念范畴)之间的关系,但给出 的解释,更多是假设,而不是验证。要验证这些 关系,确定关系的性质及作用机制,还需开展大 量的实证研究。而本研究所建构的"失地农民再 就业培训决策机制"这一实质理论,包含着14个 关系假设。这些关系假设,在促进我们对失地农 民再就业培训决策行为理解的同时,也为更进一 步的研究指出了方向。下一步可围绕"这些关系 是否存在""如果存在,这些关系的性质是什么, 是不是因果关系""各种关系之间,存在着什么样 的路径"等问题开展一系列的实证研究。

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# 视觉注意离散性的实验范式*

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摘 要 注意离散性是注意间歇性地采集外界信息的特性。文章综述了视觉注意离散性的 4 种实验范式:(1) 车轮错觉范式,刺激强度大、实验条件少、被试任务量小,较早地证实了视觉注意的离散性;(2)视觉探测范式, 同时观察了被试的行为表现与电生理信号,确定了视觉注意离散性与神经振荡的关联;(3)线索靶子范式和视 觉搜索范式,通过系统地变化 SOA 大幅提高了行为数据的时间分辨率,直观地探测到注意离散性调制的行为 振荡。

关键词 视觉注意的离散性;车轮错觉范式;视觉探测范式;线索靶子范式;视觉搜索范式 分类号 B842

#### 1 引言

一个朋友从远处走来时,我们看到他自然地 经过了沿途的每一个位置, 所以主观意识上觉得 注意在时间维度上似乎也是连续的。但实际上, 这种意识的连续性并不能证明注意的连续性。注 意可能每隔几十毫秒采集一次信息,进而构建了 整体的知觉,同时又保证了意识状态的连续性 (VanRullen & Koch, 2003)。"在时间维度上, 注意 是连续还是离散地采集外界信息"是注意领域中 亟待解决的问题之一(Buschman & Kastner, 2015; Klimesch, 2012)。近期, 诸多研究表明, 注意并非 连续地而是间歇性地加工外界信息(Busch & VanRullen, 2010; Landau & Fries, 2012; Song, Meng, Chen, Zhou, & Luo, 2014; VanRullen, Carlson, & Cavanagh, 2007)。注意的这种特性被称为"注意的 离散性", 指在精细的时间尺度上, 注意间歇性地 采集外界信息的特性,即"采集"、"停止"、"采集", "停止".....,如此循环往复(VanRullen et al., 2007)。

为了精细地观测注意的离散性,研究者们不 仅采用高时间分辨率的脑电(Busch, Dubois, & VanRullen, 2009; Busch & VanRullen, 2010; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009)、脑磁技术 (Landau, Schreyer, van Pelt, & Fries, 2015), 以及 优化经典注意研究范式等手段(Benedetto, Spinelli, & Morrone, 2016; Dugué, McLelland, Lajous, & VanRullen, 2015; Fiebelkorn, Saalmann, & Kastner, 2013; Landau & Fries, 2012; Macdonald, Cavanagh, & VanRullen, 2014; VanRullen, Reddy, & Koch, 2005), 提高原始数据的时间精度,还利用时频分析的方 法挖掘出了数据中的隐含信息(Song et al., 2014)。 文章综述了视觉注意离散性的实验范式,包括车 轮错觉范式、视觉探测范式、高时间分辨率的线 索靶子范式和视觉搜索范式, 以期为研究者提供 一个新的研究视角。

#### 2 车轮错觉范式

当个体观看旋转的轮盘时(如图 la),若轮盘 转速较慢,则会知觉到正确的旋转方向;但,当 转速增大到一定程度时,却会知觉到一个慢速的 反向运动,该现象被称为车轮错觉(The wagonwheel illusion, WWI),诱发车轮错觉的最小旋转 频率为错觉的临界频率(Purves, Paydarfar, & Andrews,

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1996)。该错觉广泛地存在于日常生活中,例如, 当个体观察高速旋转的车轮或者飞机螺旋桨时, 有时可看到慢速的反方向运动。依据尼奎斯特定 理¹,该错觉的存在说明了以下两点:第一,个体 采集外界信息的过程不是连续的,而是离散的; 第二,车轮错觉是采样过程中的混叠现象²(Kline, Holcombe, & Eagleman, 2004; Purves et al., 1996)。 然而此种采样的离散性可能是运动知觉系统的特 性,也可能是注意的特性。研究发现,车轮错觉的 临界频率是可变的,注意不仅影响车轮错觉出现 的概率还影响临界频率的大小(Macdonald et al., 2014; VanRullen et al., 2005)。因此,是注意的离散性导 致了车轮错觉,同时车轮错觉的研究也说明了注 意是一个离散的系统。自此,车轮错觉范式成为 注意离散性研究的重要范式之一。

该范式中,研究者让被试观看一个或多个旋转的轮盘(约 60 s),实验过程中,被试需要持续追踪轮子的旋转方向,并通过按键报告(如图 la)。若被试知觉到的方向与轮子的旋转方向一致则为正确,若不一致则为错误,该错误标志着车轮错觉的发生,并可作为车轮错觉量的指标。研究中,可通过观察不同注意条件下错觉的有无以及错觉量的大小,以确定注意对车轮错觉的调制作用(如图 lb)。并且,可通过改变轮盘的转速、空间频率、个数,观察不同条件下轮子错觉的临界频率,并依据此频率推断出注意的采样频率。

研究发现,运动刺激处于注意中心时,个体 最容易产生错觉;而用快速序列呈现任务(Rapid Serial Visual Presentation, RSVP)将被试的注意力 从运动刺激上移开时,错觉发生的概率大大降低 (如图 1b) (VanRullen et al., 2005)。这表明注意与 否极大地影响了车轮错觉。不仅如此,随着轮子 数目增多,被试注意资源被分配至多个位置,错



图 1 车轮错觉范式程序与主要结果 注:(a)实验中向被试呈现 10 Hz 顺时针旋转的车轮刺激, 让 被试判断轮子的旋转方向。结果发现, 被试时而知觉到真 实方向(顺时针旋转), 时而知觉到错觉方向(逆时针旋转)。 (b)当要求被试注意车轮刺激时(注意条件), 车轮错觉明显 产生; 当使用 RSVP 任务分散被试注意时(非注意条件), 错 觉量大大降低(b 图, 引并改自 VanRullen 等(2005), Copyright (2005) National Academy of Sciences, U.S.A.)。

觉出现的时间频率也发生了显著的变化。只注意 一个轮子,当它旋转的时间频率约为10 Hz时,车 轮错觉最明显,而随着车轮数量的增多,产生错 觉的临界频率逐渐降低。注意 4 个轮子时, 其时 间频率在 5 Hz 左右错觉最容易发生(Macdonald et al., 2014)。这也可以证明车轮错觉是由注意离散 采样导致。值得注意的是,上述两个研究以及 Purves 等(1996)都发现车轮错觉最明显时,车轮 旋转的时间频率约为10Hz。据此,研究者利用傅 立叶能量模型进行推测得出注意本身离散采样的 频率约为13Hz:每当轮子旋转1/2周期时注意采 集一次信息(此时注意采样频率恰巧是轮子旋转 频率的尼奎斯频率), 被试知觉发生错误可能性为 50%; 然而若在注意两次采集之间轮子旋转了 3/4 周期(此时注意采样频率低于轮子旋转的尼奎斯 特频率),注意对轮子运动信息的采集发生了混叠, 极易产生错觉。由于车轮错觉在约 10 Hz 时极易 发生,因此研究者推测注意离散性的周期约为 13 Hz  $(10 \text{ Hz} \times 4/3)$  (VanRullen, Reddy, & Koch, 2010)_o

除行为学研究发现车轮错觉是由注意离散性

¹ 尼奎斯特定理规定离散系统的采样频率需高于被采样信 号的最高频率 2 倍,否则会出现混叠现象。

² 混叠现象是指,对连续信号进行等间隔采样时,如果不能 满足尼奎斯特定理,采样后信号的频率就会重叠,即高于 采样频率一半的频率成分将被重建成低于采样频率一半的 信号。例如,太阳东升西落的周期是 24 小时,如果每隔 23 个小时拍摄一张太阳位置的照片,那么拍出来的照片所 显示出来的规律就成了太阳西升东落,周期会变成 23× 24 h,这种虚假的现象就称为混叠。运动视知觉中存在混叠 (Purves et al., 1996)。

决定外, EEG、rTMS 以及 fMRI 研究证明参与注 意过程的右侧顶叶区域与该错觉密切相关(Reddy, Rémy, Vayssière, & VanRullen, 2011; VanRullen, Pascual-leone, & Battelli, 2008; VanRullen, Reddy, & Koch, 2006)。面对同样的轮子刺激, 当被试的 知觉状态在真实方向与错觉方向(与轮子的真实 旋转方向相反)之间转换时,顶叶电极记录到的 13 Hz 的脑电信号发生明显变化(VanRullen et al., 2006)、这与行为学研究的推测吻合(VanRullen et al., 2010)。该研究表明在顶叶中记录到 13 Hz 脑电信号可以作为车轮错觉发生的生物标记,并 可以用 13 Hz 信号的强弱预测错觉的发生。在随 后的 fMRI 研究中, 研究者也发现, 错觉状态下, 被试的右侧的顶叶以及颞叶中部区域(MT+)显著 激活(Reddy et al., 2011)。更重要的是, 当采用重 复经颅磁刺激抑制右侧顶叶时,无论刺激呈现在 左侧视野还是右侧视野,错觉效应显著减弱。然 而,干扰左侧顶叶却不能改变错觉效应(VanRullen et al., 2008)。因此, 车轮错觉是一种依赖于右侧顶 叶的视觉现象。

车轮错觉的研究有力地反驳了"注意持续采 集外界信息"这一观点,证明了"注意离散性"的存 在,并巧妙地推算出注意的采样频率约为13 Hz。 自此,研究者们开始重新思考注意在时间维度上 究竟如何展开(VanRullen, Zoefel, & Ilhan, 2014)。 然而,该范式并未在时间维度上精细地操控注意, 故只能定性地观察注意离散性带来的后果,以此 间接地研究注意离散性及其规律,而不能直接观 测到注意离散性的周期性变化(冯永辉,彭运石, 2016)。但是,该范式所采用的刺激强度远高于阈 限,并且反向旋转的错觉极易被知觉到,故被试 能够准确高效地完成实验任务。另外,该范式实 验设置简洁,任务量小。上述两点使车轮错觉范 式在注意离散性的研究中具有不可替代的作用。

#### 3 视觉探测范式

当刺激强度降低至阈限水平时,虽然外界刺激强度恒定,但被试的检测能力并不稳定,在有些试次中能够成功探测到刺激的出现(击中),在 另外一些试次中则不能(漏报)。通过对比击中和漏 报试次的范式称为视觉探测范式。注意的离散性 不仅会导致个体采集外界信息时发生混叠(车轮 错觉),同时,也会影响个体对刺激的探测能力。因 此,视觉探测范式也被用来探讨注意的离散性。该 范式假设,微弱的刺激出现在注意采集窗口内会 更容易被探测,而错过注意采集的时窗则易被漏 报(如图 2a)(张雪,袁佩君,王莹,蒋毅,2016; Jensen, Bonnefond, & VanRullen, 2012)。研究者需先找到 与探测能力密切相关的指标,然后验证其是否受 到注意调控。以此,确定当下注意状态和探测能 力的关系。由于"注意的离散性"观点认为注意在 时间维度上的状态是变化的(采集或停止),所以 该指标首先应该具有很好的时间分辨率。从这一 点来讲, EEG 和 MEG 信号具有不可多得的优势。



注:(a)实验中向被试呈现一个微弱的正弦光栅,让被试判 断刺激是否出现。若刺激出现在注意振荡的某个特定相位 时,该刺激能够被探测到(击中);反之,则不能探测到(漏 报)。(b)击中与漏报试次能量谱与相位谱的差异性检验结 果。刺激出现前,成功探测试次中的 alpha 频段能量明显低 于漏报试次;同时,该频段的相位差也最大(b 图,引并改 自 Busch 等(2009))。

视觉探测范式中,被试需重复完成探测微弱 刺激的任务。由于击中试次与漏报试次中,外界 刺激恒定,所以,通过两类试次的 EEG 或 MEG 信号的差异,即可确定与探测能力相关的电生理 指标。最后,再通过操控注意,来确定该指标以及 被试的探测能力是否受到注意调控。

Hanslmayr 等(2007)采用视觉探测任务考察 个体对微弱刺激的探测能力时发现,刺激出现前 个体脑内的神经振荡与觉察表现(击中或漏报)有 关。在击中试次中,刺激出现前,被试脑活动中
alpha 能量较低, 而漏报试次中 alpha 能量更高 (Hanslmayr et al., 2007)。虽然该研究说明对单个 微弱刺激的探测活动与神经振荡有关, 但是此种 相关并没有出现在神经振荡的相位与探测能力之 间、仅发生在神经振荡的能量与探测能力之间。 该能量同时反映了刺激出现前数个振荡周期内 (500 ms)的神经活动情况、因此不能准确地预测 随后的行为表现。而相位可以表示每个时刻的神 经活动, 所以相位是更好的预测指标。为了进一 步探究神经振荡的相位与觉察表现的关系,研究 者缩减了靶刺激呈现时间(从 57 ms 降至 12 ms、6 ms), 从而减少了由于刺激出现和消失对神经振荡相位 产生的巨大干扰。基于此改进,研究者发现除 alpha能量外, alpha相位可以更好地预测被试完成 任务的表现:在击中试次和漏报试次中,刺激出 现前神经振荡的相位相反(如图 2b) (Busch et al., 2009; Mathewson et al., 2009; Sherman, Kanai, Seth, & VanRullen, 2016)。除了外界的微弱刺激外、由 TMS 诱发的光幻视效应3同样与神经振荡密切相 关。Dugué, Marque 和 VanRullen (2011)用经颅磁 刺激(Transcranial Magnetic Stimulation, TMS)干 扰视觉皮层(干扰会使被试出现光幻视)的同时记 录脑电(Dugué et al., 2011)。结果显示 TMS 脉冲释 放前 400 ms 内的 alpha 节律的相位与被试能否知 觉到光幻视发生了共变,即,脑内神经振荡的不 同相位决定了光幻视现象受到促进或者抑制。该 研究证实了神经振荡的相位、神经兴奋性和知觉 的因果关系:神经振荡使大脑产生了离散的、周 期性的兴奋时间窗, 而外界刺激仅出现在某个特 定的相位才能被知觉到。

上述研究没有直接操控注意,所以不能说明 神经振荡是通过注意调制行为表现。为解决此问 题,Busch和 VanRullen (2010)操控注意,观察脑 神经活动和靶刺激觉察的行为表现。研究发现, 仅注意条件中,刺激出现前的 alpha 频段的能量 和相位才可预测行为表现(击中或漏报),而未注 意条件中并不存在这种关系(Busch & VanRullen, 2010)。该研究进一步证明了神经振荡是通过视觉 注意调制行为表现,也确认了 Busch 等(2009)和 Mathewson 等(2009)采用探测任务观察到的是注 意振荡。Landau 等(2015)首次使用脑磁图更直接 地考察了对两个位置注意的离散性特征。实验中, 靶刺激随机出现在两个光栅上,被试需要持续注 意这两个光栅。结果发现对侧半球距状沟、舌回 以及楔前叶内的神经振荡(4 Hz)的相位与被试探 测能力相关,刺激出现前该频段的相位可以解释 行为表现变异的 14.5% (Landau et al., 2015)。

视觉探测范式同时观测被试的电生理信号与 行为表现,利用该范式的研究不仅证明了注意离 散性对视觉探测能力的影响,并且发现了注意离 散性可能的生理基础:神经振荡的能量和相位。 视觉探测范式的相关研究还考察了对一个或者两 个对象的探测行为表现与神经振荡的关系:刺激 出现前神经振荡的相位处于特定位置或者能量较 低时,被试更容易觉察到刺激的出现。更重要的 是,神经振荡与探测能力的相关仅在注意条件下 才稳定存在。这表明、视觉探测范式中的神经振 荡极有可能是注意离散性的神经基础。该范式的 优势在于提供了操控注意离散性的可能途径,即 通过 TMS 干扰神经振荡。然而,利用该范式所观 察到的注意离散性、神经振荡对行为表现的调制 方面,其结果比较粗略(仅分为击中与漏报)。如果 神经振荡是注意离散性的神经基础,那么注意强 度会随着神经振荡而变化,注意的行为表现也应 该随着时间起伏,出现类似神经振荡的行为振荡。

#### 4 线索靶子范式

Posner 和 Cohen 曾通过变换线索与靶子的时 间间隔(stimulus onset asynchrony, SOA)探讨了注 意的时间特征(Posner & Cohen, 1984)。他们发现 当SOA小于约250 ms时,注意可以促进线索化位 置的信息加工,当 SOA 大于约 300 ms 时,注意会 抑制线索化位置的加工,这是早期研究发现的注 意在时间维度上的变化过程。然而,研究设计中 SOA 选取数量少(SOA: 0 ms、50 ms、100 ms、200 ms、 300 ms)、时间精度低,不能反映出注意在更加精 细时间尺度上的变化。同时,在数据处理和研究 方法上还存在两方面的局限: 第一, 大量的空间 注意的研究是将多个试次的行为反应平均, 而忽 略试次间的变异,这就导致一些快速变化的节律 特征被掩盖(Cohen & Maunsell, 2011; VanRullen et al., 2007)。第二, 行为的反应时和正确率指标反 映的是所有神经活动的总和, 仅能体现认知活动

³ 光幻视效应:视觉皮层接受经颅磁刺激后,个体会产生瞬间的光感觉(Romei et al., 2008)。

的最终结果。这些局限阻碍了早期研究者探索注 意的节律特征。

近期,研究者提高了线索靶子范式的时间分 辨率,打破了传统认知任务不能精细研究注意离 散性的局限, 直接在行为中发现了振荡模式(Dugué, Roberts, & Carrasco, 2016; Fiebelkorn et al., 2013; Landau & Fries, 2012; Song et al., 2014)。该方法在 线索和靶子呈现之间设置多个不同时间间隔(通 常设置的 SOA 水平超过 50 个), 以此提高行为研 究的时间分辨率。此方法的基本逻辑如图 3a: 假 设对左右两个光栅的注意存在固定的离散周期, 而注意可能以任意的相位振荡,故我们无法检测 此时注意周期的相位,但是,当在左侧或右侧呈 现一个较为突显的线索时,该线索就会捕获被试 的注意,进而重置之前杂乱无章的相位,这样通 过测量线索出现后的各个不同时间点上对靶刺激 知觉时的行为表现,即可探索注意的周期性规 律。值得注意的是,无论突显线索将注意重置到 何种相位,只要试次间重置后的相位相同,该方 法即可成功检测到注意的振荡模式。

Landau 和 Fries (2012)首次采用这一方法开

创性地探索了注意在两个位置动态波动的过程。 实验中,研究者给被试呈现左右两个光栅,在某 一位置短暂闪现线索后呈现靶刺激(如图 3b)。线 索的出现重置了自发性注意振荡的相位, 使原本 隐藏在行为里的随机注意节律变得可测量。研究 者计算出每种 SOA 水平内的探测任务的正确率, 结果发现, 被试的正确率随着 SOA 的变化呈现周 期性的变化(如图 3c), 该变化模式与神经振荡极 为相似。具体而言, 当线索出现在右视野内时, 注 意以4Hz反相位的模式在两个客体间波动;而左 视野呈现线索时,对两个位置出现靶子的觉察行 为在 6~10 Hz 的频段(8 Hz 左右)达到峰值。研究 者认为8 Hz 和4 Hz 频段的注意节律有着共同的 神经源, 但是由于右侧大脑负责对两侧视野呈现 的刺激进行注意, 左侧大脑只负责右侧视野呈现 的刺激,故而左右视野的振荡行为出现差异。相 对于左侧,右侧呈现的线索可以激活两侧的大脑 与注意相关的区域,使其重置的能力更强,该线 索将所有试次的注意相位皆重置为同一相位,因 此两侧原本以8Hz速度振荡的注意节律受到右侧 强线索的"干扰"后, 就降低成 4 Hz 反相位的振荡



#### 图 3 高时间分辨率线索靶子范式

注: (a)该范式的理论假设:由于自发性节律的相位无规律,所以在行为中很难直接观测自发性节律。但是,如果实验者将 自发性节律重置(如图通过呈现一个突显的线索重置注意相位),使其有规律,就可以借此探究空间注意行为中的节律。(b) 该范式的实验流程:实验中,通过外侧白点标记线索化位置,随后在光栅上呈现一个微弱的靶刺激(局部的对比度降低)。如 图所示,红色标记为线索化条件,蓝色标记为非线索化条件。(c)Landau 和 Fries (2012)的实验结果。在线索化和非线索化两 种条件下,被试的探测能力此起彼伏,表现出行为振荡(灰色阴影区域)。(引并改自 Herbst 和 Landau (2016), Copyright (2016) with permission from Elsevier.)

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模式在两个位置采集信息;而相对较弱的左侧线 索虽然在试次内可以重置注意相位,但并不能保证 每个试次内重置后的相位相同,所以在叠加后的 结果中,注意仍表现出 8 Hz 的振荡模式(Landau & Fries, 2012)。该研究从两个角度为注意的离散性 提供了重要支持:第一,注意离散性的具体表现 模式为正弦波,与神经振荡极为相似;第二,与 注意相关的行为振荡频率(8 Hz)和视觉探测任务 中发现的与注意相关的神经振荡频段(Busch & VanRullen, 2010)极为相近。

Landau 和 Fries (2012)证明了空间注意的离 散性之后, Fiebelkorn 等人(2013)同样利用此方法 探究客体注意的离散性。靶刺激可能出现在线索 化位置、同客体非线索化位置以及不同客体非线 索化位置,以此更好地分离空间位置和客体两个 因素。结果显示, 靶子出现在线索化位置和同客 体非线索化位置时, 探测的正确率在 8 Hz 的频段 上波动, 而对于两个非线索化位置出现的靶子探 测正确率是以 4 Hz 反相位的模式振荡, 即注意在 这两个位置来回的切换(Fiebelkorn et al., 2013)。研 究首次通过心理物理法确定了客体注意的离散 性。值得注意的是, Fiebelkorn 等(2013)的研究中 有 75%的试次靶刺激出现在了线索化位置, 而 Landau 和 Fries (2012)的研究中此概率仅为 50%, 此处不同会导致内源性注意的变化,进而影响注 意振荡的行为表现。

从数据处理角度看,上述两篇研究均使用快 速傅立叶变换(Fast Fourier transform)分析注意振 荡的频率。此方法分析频域信号时假定振荡的信 号是稳定的,因此它不能反映随时间变换的频率 信息, 而小波变换(wavelet transform)的方法更适 于分析非平稳的信号,可能会发现以往研究中未 观测到的结果(Zoefel & Sokoliuk, 2014)。Song 等 (2014)使用了这种方法,对完成线索靶子任务的 反应时进行分析,结果显示反应时数据中同样存 在 8~20 Hz 的振荡模式,并且发现了高频能量和 低频相位的耦合(Song et al., 2014)。这表明注意振 荡的行为表现不仅体现在正确率上, 也存在于反 应时之中(Huang, Chen, & Luo, 2015; Song et al., 2014)。该研究拓宽了行为振荡的表现形式,同时 也证明了行为振荡不仅表现在任务较难时的正确 率上(Landau & Fries (2012)、Fiebelkorn 等(2013) 中靶刺激为阈限强度),在难度较低的任务中也同 样可以观测到(Song 等(2014)中正确率约为 98%)。

线索靶子范式巧妙地克服了视觉探测范式中 行为表现水平单一的局限. 成功地观测到行为表现 的振荡模式,成为研究注意时间特性的一个重要 手段。利用该范式的研究不仅观测到了注意离散 性在正确率和反应时上的表现形式,还证实了空间 注意和客体注意二者都具有离散性、为注意离散的 普遍性提供了重要依据。然而, 该范式也存在不 足:该范式假设"注视点之后的突显线索重置了原 本杂乱无章的注意振荡", 而突显线索本身是一 个额外事件,随后测量到的行为振荡有可能由突 显线索诱发而非注意本身具有的特性。针对此不 足,研究者去除突显线索仍旧发现了注意振荡模 式(Landau et al., 2015), 再次证明线索靶子范式 是研究注意离散性的良好手段。另外, 该范式中 被试注意的位置或者客体较少、远离真实场景。 真实生活中, 外界环境复杂多变, 个体需要在多 个物体或者多个空间位置上搜索目标。线索靶子 范式中仅有两个物体(位置),注意在两者间来回 波动。该范式下,研究者在两个物体(位置)上均可 观测到注意振荡的行为模式, 但是, 当物体个数 增加时,下一刻要关注哪个物体(位置)就变得不 可测量,也难以保证每个试次中注意转移的顺序 相同。针对这一情境、采用更加生态化的方法就显 得尤为重要。同时,研究注意在多个物体(位置)上的 采集模式、将会为注意离散性提供更多的证据。

#### 5 视觉搜索范式

视觉搜索范式是指在被试搜索目标的同时呈现分心物的研究方法,是注意研究的经典范式 (Wolfe, 2010)。该范式同时呈现多个物体,任务情 景与日常生活更加类似,可以探究"存在多个物 体时注意的离散性"。

如上文所述,当物体个数增加,注意在下一 刻将要指向哪个物体(位置)变得不可测量,并且 不能保证每个试次中个体的注意转移顺序相同。 Dugué 等人巧妙地增加了一个回忆任务用于解决 此问题。同时,与高时间分辨率线索靶子范式类 似,研究者也系统变化搜索屏和回忆项目呈现的 时间间隔来提高时间分辨率(Dugué, McLelland, et al., 2015)。此范式中,首先呈现多个搜索项目 (搜索屏),间隔一段时间后,在先前搜索过的位 置中呈现两个记忆项目,并随后呈现掩蔽项降低

记忆项目的可见性。呈现结束后,被试需要同时 完成视觉搜索任务(搜索项目中是否呈现了字母 T)和记忆任务(在若干项目中识别出记忆项目) (如图 4a)。该范式假定:搜索过程中,每个搜索项 目所占用的注意资源会决定随后该位置呈现的字 母(记忆项)被回忆出的概率。假设对于搜索阶段的 任意两个位置 A 和 B, 记忆项目出现在位置 A 时 被回忆到的概率是 P1, 呈现在位置 B 时被回忆的 概率是 P2。两个项目被同时搜索到的概率是  $P_{hoth} =$ P1×P2, 都不被搜索到的概率 Pnone = (1-P1)×(1-P2) (如图 4b)。又因为, Pboth 和 Pnone 均可通过被试 在回忆任务中正确率测得。由此,便可通过公式 求出 P1 和 P2。依照高时间分辨率线索靶子范式 的思维,系统地变化搜索屏和回忆项目呈现的时 间间距, 就可以观察到 P1 和 P2 随着时间变化的 周期。如此,视觉搜索任务就可以同时展现注意 离散性在时间和空间上的表现(如图 4c)。

Dugué 等人利用这种范式成功地证明了注意 的离散性,更重要的是,研究者通过对数据的深 入分析发现:注意在各个位置离散加工的频率约 为7 Hz,取得与线索靶子范式较为一致的研究结 果。电生理的研究表明搜索任务中的注意振荡与 6 Hz 的神经振荡密切相关,研究者用 TMS 干扰 6 Hz 的神经振荡之后,发现行为振荡受到影响,进而 直接证明了注意振荡是神经振荡所致(Dugué, Marque, & VanRullen, 2015)。然而,对恒河猴动眼区(Frontal eye fields, FEF)神经元细胞直接记录发现注意与 18~34 Hz 的神经振荡有关(Buschman & Miller, 2009)。两个研究结果的差异可能是研究对象(猴子 和人)、任务难度以及研究手段(局部神经元记录和 头皮表面脑电记录)不同。但无论注意与何种节律 相关,这些研究皆说明视觉搜索任务中注意离散 性和神经振荡的相关。

利用视觉搜索范式与记忆任务的结合,可以 测量搜索过程中每个搜索项占用的注意资源,还 可以通过系统地改变 SOA 探索注意振荡。相关的 行为学研究证明了,即便当搜索项目增加至 4 个 时,注意仍旧以振荡的形式在多个项目间离散采 样。电生理的研究证明了行为振荡受神经振荡的 调制。然而,搜索任务中靶子和分心物具有相同



#### 图 4 Dugué 等(2015)实验及结果

注:(a)实验中被试需要完成两个任务:判断搜索屏中是否有 T 出现以及识别记忆项中出现的字母。(b)在记忆项识别任务中, 可算出两个项目都回忆出来的概率(Pboth),两个项目都未回忆出来的概率(Pnone),再利用图中公式求得更多注意位置和更少 注意位置出现记忆项时被试识别的正确率。(c)更多注意位置和更少注意位置出现记忆项目时被试的正确率随时间的周期性 变化。(引并改自 Dugué, McLelland 等(2015)) 特征(如 Dugué, McLelland 等(2015)实验中靶子和 分心物都是红色),这一操作会增加实验难度。当 二者没有共同特征时,是否还能显现注意的离散 特征,这还有待于进一步研究。值得注意的是,虽 然视觉搜索范式中靶刺激项目增加,但注意仍以 6~7 Hz 离散采集多个空间位置的信息。因此,线 索靶子范式和视觉搜索范式的研究共同提示,注意 可能存在其内在的固定节律(VanRullen, 2013, 2016)。

#### 6 小结和展望

本文综述了视觉注意离散性研究的 4 个范 式。车轮错觉范式中所采用的刺激强度远高于阈 限, 故极易被知觉到。早期研究者正是利用该范 式证明了注意离散性的存在。视觉探测范式同时 考察电生理信号和行为表现,可以探究注意离散 性的神经机制。这两种范式在没有重置注意相位 的情况下,直接观察由于注意离散性导致的行为 表现,实验设置简洁,任务量小,但却不能在精 细的时间尺度上观测注意离散性的振荡模式。线 索靶子范式通过突显线索重置了注意的相位,并 系统地变化 SOA, 直观地观测到注意离散性调制 的行为表现(正确率和反应时的周期性变化)、以 及注意离散性的振荡模式。通过添加一个额外的 记忆任务,视觉搜索范式进一步把线索靶子范式 推广至更加生态化的场景中, 拓宽了注意离散性 的生态效度。然而、由于系统地变化 SOA、线索 靶子范式和视觉搜索范式存在实验条件繁多、被 试任务量较大等问题。

尽管研究者采用上述范式证明了视觉注意的 离散性的存在,但仍有以下几方面问题亟待厘 清:首先,线索靶子范式和视觉搜索范式的研究 发现注意振荡的节律为 6~8 Hz,但各个范式的研 究中观测到的注意离散性相关的节律并不完全一 致。因此"注意振荡是否存在固有节律"这一问题 还亟待研究。其次,虽然已有研究表明神经振荡 可能是注意离散性产生的神经基础(Busch & VanRullen, 2010),但是由于研究方法的局限,注 意离散性的神经机制尚不明确。最后,本文提及 的研究均是关于视觉通道内注意离散性的研究成 果,但是对外界环境信息的节律性加工广泛存在 于多种感觉通道中(Uchida, Kepecs, & Mainen, 2006)。 因此,"注意的离散性现象是否存在于其它感觉通 道中"也有待探索。

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#### Experimental paradigms for discrete attention in visual domain

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Abstract: The spotlight of attention is intrinsically rhythmic, which discretely sample a single or multiple objects. This phenomenon is called discrete attention. Here we summarized four paradigms used to investigate discrete attention in visual domain. In the wagon-wheel illusion paradigm, motion direction illusion is experienced. This paradigm is adopted to demonstrate the discreteness of attention. In the visual detection paradigm, participants are asked to detect the near-threshold stimuli, which is used to investigate relationship between neural oscillation and discrete attention. In the high time-resolved cue-target paradigm, a target occurs after a varying interval following a peripheral cue; while the target is embedded among distracters in the visual search paradigm. These two paradigms are developed to vividly show behavioral oscillation patterns.

Key words: discrete attention in visual domain; wagon-wheel illusion; cue-target paradigm; visual detection; visual search



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## 未来自我连续性及其对个体心理和行为的影响*

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摘 要 一个人将现在自我和未来自我联系在一起的紧密程度反映了他/她在时间维度上自我连续性的强度, 即未来自我连续性。个体如何看待其现在自我与未来自我之间的连续和一致程度对个体的心理和行为有重要 的影响,特别是在跨期决策、储蓄和消费、学业成就领域、社会行为和健康领域等方面。未来研究可深入探 讨未来自我连续性的神经基础及其影响因素,并进一步拓展未来自我连续性相关的应用研究。 关键词 未来自我连续性;跨期决策;时间折扣

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#### 1 引言

科学心理学对自我的探索和研究始于心理学 之父威廉·詹姆斯(William James)。在他的名著《心 理学原理》中,詹姆斯将自我分成主体我(I)和客 体我 (me)、进而又将客体我分为物质自我 (material self)、社会自我(social self)和精神自我 (spiritual self)。此后的一个多世纪,心理学家从不 同的视角对自我进行了进一步的区分和大量的研 究,比如:真实自我(true self)和虚假自我(false self) (Winnicott, 1965); 现实自我(actual self)和理 想自我(ideal self) (Rogers, 1961); 个体自我 (individual self)、关系自我(relational self)和集体 自我(collective self) (Sedikides & Brewer, 2002); 独立的我 (independent self) 和相依的我 (interdependent self) (Markus & Kitayama, 1991); 外显自我(explicit self)和内隐自我(implicit self) (Greenwald, McGhee, & Schwartz, 1998)等等。其 中,一个重要的区分是以时间维度为基础,将自 我分为过去自我(past self)、现在自我(present self) 和未来自我(future self) (Parfit, 1971; Welch-Ross,

2001)。近年来,这种基于时间维度区分的自我得 到了研究者越来越多的关注。例如,研究者们发 现个体对未来自我的加工不同于现在自我, 对未 来自我的加工属于抽象的、高层次的加工;而对 现在自我的加工属于具体的、低层次的加工(Wakslak, Nussbaum, Liberman, & Trope 2008; Liberman & Trope, 2014; Trope & Liberman, 2003). Hershfield 及其团队则指出个体倾向于将未来自我加工成与 现在自我关系不大的陌生人, 在加工未来自我时 激活的脑区也与现在自我不同 (Hershfield, Wimmer, & Knutson, 2009)。虽然个体对不同时间 维度上自我的加工存在差异,但是将未来自我看 作是现在自我在时间维度上的连续对个体具有重 要的意义。研究者们发现个体对其现在自我与未 来自我之间的连续和一致程度(即未来自我连续 性, future self-continuity)的认识对个体与时间维 度有关的决策行为(例如时间折扣, temporal discounting, Hershfield et al., 2009b)、学业成就方 面(Adelman et al., 2016)、社会行为(如不道德行为, Hershfield et al., 2012; Sheldon, & Fishbach, 2015) 和健康行为方面(Rutchick, Slepian, Reyes, Pleskus, & Hershfield, 2018)等有重要的影响作用。有关未 来自我连续性的研究正成为自我研究领域的一个 前沿热点。本文主要介绍未来自我连续性的概念 内涵,揭示未来自我连续性对个体心理和行为的 影响,并基于此提出未来可能的研究方向。

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#### 2 什么是未来自我连续性?

#### 2.1 未来自我连续性的概念内涵

#### 2.1.1 概念的提出

早在 1971 年, 哲学家 Derek Parfit 就提出个 体的自我认同可以延伸至过去和未来(Parfit, 1971)。一个人过去的经历会影响其对自我的认识, 而个体过去的经历和对过去自我的认识会慢慢被 个体内化, 成为自我认同的一部分; 同样, 个体 对未来的自己的看法以及对未来生活的想象也会 影响个体现在的心理和行为,并被纳入自我认同 当中(D'Argembeau, Lardi, & Van der Linden, 2012)。 据此, Chandler (1994)将自我连续性(self-continuity) 定义为个体在时间维度上将过去自我、现在自我 和未来自我知觉为一个整体的程度。当个体感受 到过去、现在和将来的自我是同一个自我时,他/ 她的自我认同在时间维度上就是连续、一致的 (Chandler, Lalonde, Sokol, & Hallett, 2003)。与 Chandler 不同, Hershfield 等(2009b)更关注个体对 现在自我和未来自我的看法, Hershfield 等人于 2009 年提出未来自我连续性的概念, 用其描述个 体对其现在自我与未来自我之间连续和一致程度 的认识,同时提出了未来自我连续性假设(future self-continuity hypothesis), 指出个体倾向于将未 来的自己看作是与现在的自己毫无关联的陌生 人。他们采用功能性磁共振成像(fMRI, functional magnetic resonance imaging)的技术,让被试判断 所呈现的特质词是否可以用来描述其现在的自己 和未来的自己,发现个体加工现在自我时前喙扣 带皮质(rostral anterior cingulate cortex, rACC)出 现了较为显著的激活,而加工未来自我时大脑激 活的区域与加工陌生人时更为相似。

#### 2.1.2 未来自我连续性的涵义及模型

未来自我连续性¹指个体将现在自我和未来 自我联系在一起的紧密程度(Hershfield et al., 2009b; Hershfield, Garton, Ballard, Samanez-Larkin, & Knutson, 2009a)。未来自我连续性高的人认为其未来自我 (如 5 年或 10 年后的自己)与现在自我之间有很多 相似之处,在想象未来的自己时会有更生动清晰 的画面,对未来的自己也有着更为积极的评价。 Hershfield (2011)提出了未来自我连续性模型(见 图 1), 指出相似性(similarity)、生动性(vividness) 和积极性(positivity)三个方面共同影响未来自我 连续性,并进而影响跨期决策。其中,相似性主要 指一个人眼中未来自我与现在自我之间的相似程 度。相似性越高,未来自我连续性越强。生动性 主要指个体在加工未来自我时, 头脑中出现的画 面的生动和形象程度。当一个人在想象未来某个 时间点的自己时,其想象出的画面越清晰、生动, 他/她越容易与未来自我感同身受(Klineberg, 1968)。积极性主要指个体在想象未来自我与现在 自我之间的关系时感受到的未来自我的积极程 度。个体将未来自我看得越积极, 就越容易将未 来自我与现在自我联系在一起 (Zhang & Aggarwal, 2015)。虽然未来自我连续性模型对目 前的有关研究有一定的指导作用,但是此模型尚 不够完善,相似性、生动性和积极性三方面之间 的关系还不够明确。例如该模型中仅指出相似性 与生动性之间是相互影响的, 操纵个体想象未来 自我的生动性可以增强现在自我与未来自我之间 的相似性;但相似性与积极性之间的关系,生动 性与积极性之间的关系,以及三者之间是如何相 互影响的目前均尚待检验。



图 1 未来自我连续性模型(其中虚线代表待检验的关系)(Hershfield, 2011)

#### 2.2 未来自我连续性的操作性涵义

目前,有关未来自我连续性的操作性涵义主要包括从测量出发和从操纵出发两个方面。从测量出发是将未来自我连续性看作是一种特质或个体差异,主要关注如何对其准确测量;从操纵出发是将未来自我连续性看作是一种状态,主要关注如何对其进行有效操纵。

#### 2.2.1 从测量出发

Hershfield 等(2009a)在自我他人融合量表 (Inclusion of the Other in the Self scale; Aron, Aron, & Smollan, 1992)的基础上编制的未来自我连续

¹ 也有一些研究者常把未来自我连续性操作为与未来自我 的心理联结(psychological connectedness with future self) (Bartels & Rips, 2010; Urminsky, 2017)。

性问卷。如图 2 所示,在每组圆中,一个圆代表 "现在的我",另一个圆代表"未来的我",两个圆 的重合程度代表了"现在的我"和"未来的我"之间 的连续性关系,重合程度越大,代表"现在的我" 和"未来的我"之间的联系越紧密、连续性也越强。 在施测时,被试首先需要想象未来自我和现在自 我之间的关系,然后判断哪一组圆最能代表其 "现在的我"和"未来的我"之间的相似和紧密联系 程度。该问卷的测量结果可以反映不同的人在未 来自我连续性上的个体差异。这一测量方法还可 以在网络上进行施测,被试可以通过鼠标拖动两 个圆,用两个圆之间的距离表示"现在的我"和 "未来的我"之间的重合程度(Kamphorst, Nauts, & Blouin-Hudon, 2009)。

#### 2.2.2 从操纵出发

目前通常采用阅读任务、书写任务和互动任 务来操纵未来自我连续性。

一些研究者通过让被试阅读一些文本材料来 操纵被试感知到其未来自我和现在自我之间心理 联结的强度,以此来操纵未来自我连续性。例如, Bartels 和 Rips (2010)让实验组被试阅读一组人生 经历变故较少的人物故事,让控制组被试阅读人 生经历曲折变化的人物故事,借此使实验组被试 感受到自己的现在自我与未来自我在时间维度上 是连续一致的,从而成功操纵了未来自我连续 性。又如,Bartels和Urminsky (2011)让被试阅读 一段关于自我认同是否会随时间改变的描述,并 对阅读材料进行总结概括。其中,实验组被试阅 读的材料指出个体的自我认同是一致不变的,而 控制组被试阅读的材料则指出自我认同是随时间 不断变化的。这一方法也成功使被试感受到个体 的自我在时间维度上是连续的,成功操纵了被试 的未来自我连续性。

采用书写任务操纵未来自我连续性主要是让 被试根据要求进行论述或写作。例如, Hershfield, Cohen 和 Thompson (2012)让实验组被试想象并尽 可能多得列出 10 年后的自己与现在的自己之间 的相似点,控制组的被试则想象并写出10年后的 世界是什么模样, 通过描述现在的自己与10年后 的自己之间的相似点增强了被试的未来自我连续 性。Van Gelder, Hershfield 和 Nordgren (2013)则让 被试给未来的自己写信,借此增强被试想象未来 自我时的生动性程度。Zhang 和 Aggarwal (2015) 让实验组被试想象并具体描述现在自我与5年后 的未来自我之间的相似之处, 控制组被试想象并 描述现在自我与5年后的未来自我之间的不同之 处。这种方式也有效地增强了被试现在自我与未 来自我之间的紧密联系程度,进而成功操纵了未 来自我连续性。

科学家们还借用一些新兴技术或平台设计一些互动任务,操纵心理学的变量。Hershfield 等 (2011)采用浸入式虚拟现实技术(immersive virtual reality),让被试戴上特定的眼镜观看自己老年后 的头像并与其进行互动,从而增强了被试想象未 来自我时的生动性,进而增强其未来自我连续 性。Blouin-Hudon 和 Pychyl (2016)借助音频材料, 采用心理想象(mental imagery)的干预方法,让被 试去听指定的音频材料并想象未来某个时间点的 自己,这一方法成功提高了被试想象未来自我时 的生动程度,增强了被试的未来自我连续性。Van Gelder 及他的团队(2015)通过社交网站在现实生 活情境中操纵被试的未来自我连续性。研究者让



图 2 未来自我连续性问卷图示(改编自 Hershfield et al., 2009a)

实验组的被试通过 Facebook 与未来的自己成为好 友, 然后连续 7 天通过社交网站实现与未来自我 之间的互动; 相反, 控制组的被试则与现在自我 交流 7 天, 这一方法也成功操纵了被试的未来自 我连续性(Van Gelder, Luciano, Weulen Kranenbarg, & Hershfield, 2015)。

#### 3 未来自我连续性对个体心理和行为 的影响

未来自我连续性对个体心理和行为的影响主 要体现在跨期决策、储蓄和消费行为、学业成就 领域、社会行为和健康领域等方面。

#### 3.1 对跨期决策的影响

未来自我连续性对跨期决策的影响主要体现 时间折扣方面。时间折扣指个体倾向于对当前的 损益赋予更大的权重, 对未来的损益赋予较小的 权重(Hershfield et al., 2009b; 阿不来提江 等, 2015)。当一个人将未来自我和现在自我紧密联系 在一起时,他/她会对未来自我的需求赋予较大的 权重,也深知自己当前的选择会影响未来的自己, 所以当需要在"现在获得 100 元"和"半年后获得 150 元"之间进行选择时, 更容易选择半年后获得 更多的金钱、即在跨期决策中表现出较低的时间 折扣。Hershfield 等人(2011)发现未来自我连续性 可以预测跨期决策中的时间折扣, 操纵个体对未 来自我的想象和关注可以降低被试在跨期决策中 的时间折扣, 被试会为了得到更多的报酬而选择 等待。Bartels 和 Rips (2010)发现个体与未来自我 的心理联结程度可以预测其跨期决策的选择,即 与未来自我心理联结程度较强的被试, 更愿意在 跨期决策中做出对未来自我有益的决策。Bartels 和 Urminsky (2011)也开展了一系列实验研究考察 未来自我连续性对时间折扣的影响。他们发现: 当被试将未来自我看得与现在自我越相似、联系 越紧密,他们越愿意选择让未来的自己获得更多 的利益,做出更多有耐心的选择,从而表现出较 低的时间折扣。

#### 3.2 对储蓄和消费行为的影响

未来自我连续性还会影响个体的储蓄和消费 行为。Hershfield 等人(2009a)调查了现实生活中人 们的资产分配行为,结果发现未来自我连续性可 以预测人们的储蓄金额,未来自我连续性高的人 会为以后的自己存储更多的资产。Hershfield 等人 (2011)进一步通过实验操纵了未来自我连续性, 结果发现提高被试的未来自我连续性可以增加被 试为老年时的自己分配的退休储蓄金额。Bartels 和 Urminsky (2015)发现在操纵被试对金钱用途的 认识后(例如提醒被试金钱有很多用途),未来自 我连续性高的人更少表现出只考虑现在、不考虑 将来的消费行为, 也更愿意减少自己当前的花销, 例如选择购买较为便宜的商品,从而将金钱分配 到未来的其他花销上。同时, 他们还发现增强现 在自我与未来自我之间的心理联结程度可以降低 不理智的消费行为,如购买热量高的巧克力等。 此外, 未来自我连续性还会影响人们对某个商品 或品牌的态度。通过操纵被试的未来自我连续性, Zhang 和 Aggarwal (2015)发现当被试与未来自我 的心理联结较强时,他们对将来(如 5 年以后)会 拥有的商品持有更为积极的态度,揭示了未来自 我连续性对人们消费意向的影响作用。

#### 3.3 对学业成就领域的影响

俗话说"少壮不努力,老大徒伤悲"。当一个人 认为未来的自己与当前的自己是不可分割、紧密 相连的时候,他/她更有可能现在"努力",以免 将来"徒伤悲"。Adelman 等人(2016)发现:未来自 我连续性高的大学生具有较高的自控力, 而且未 来自我连续性对自控能力的影响作用可以被这些 学生对未来结果的考虑(consideration of future consequences)所中介,即未来自我连续性高的学 生会更多的去考虑他们现在的行为对自己将来的 影响, 而对未来的考虑可以进一步预测他们的自 我控制能力, 拥有较高的自控能力有助于学生获 得较高的学业成就。此外,他们发现个体的家庭 教育背景可以调节未来自我连续性对自控能力和 学业成就的预测作用:这种预测作用在父母有受 过大学及以上教育水平的学生(continuing-generation) 中显著强于那些自己是家中第一代接受大学教育 的学生(first-generation)。

除了自控能力,拖延症(procrastination)也是 影响学生学业成就的一个重要问题。现有研究发 现未来自我连续性可以影响人们的拖延倾向。很 多学生面对繁重的课业往往采取拖延的策略,面 对考试也是采取"临时抱佛脚"的态度,将学业任 务拖到截止日期或考试前才着手去做,即"患有" 所谓的拖延症。拖延症属于自我调节失败的范畴, 具有拖延症的人面对问题通常采用回避的应对策 略,虽然短时间内的拖延可能会缓解个体当下面 对的压力和负面情绪,但却会给未来的自己带去 更多的压力和焦虑(Rozental & Carlbring, 2014)。 Blouin-Hudon 和 Pychyl (2015)考察了大学生样本 中未来自我连续性与拖延倾向之间的关系,结果 发现:未来自我连续性与拖延倾向之间存在显著 负相关,即未来自我连续性低的学生有更高的拖 延倾向。而且他们发现未来自我连续性对拖延倾 向的影响主要受生动性的影响。个体想象未来自 我时越是生动形象,越容易及时完成自己的任务, 较少拖延。此外,研究者还发现让被试进行未来 指向的心理想象也可以提高被试的未来自我连续 性并降低他们的拖延倾向(Blouin-Hudon & Pychyl,

2016)。

#### 3.4 对社会行为的影响

未来自我连续性会影响个体的不道德行为、 社会不良行为(如欺骗和偷窃等)和亲社会行为等 社会行为。

首先, 未来自我连续性可以预测不道德行 为。具体表现在: 当个体认为其未来自我与现在 自我之间没有太多的相似之处时,他/她更容易做 出不道德行为,比如为了给现在的自己谋取利益 选择去撒谎, 而较少顾及这些行为对未来的自己 造成的影响(Hershfield et al., 2012; Sheldon, & Fishbach, 2015)。其次, Van Gelder 等(2013)的研究 也发现:未来自我连续性低的被试更容易去做一 些具有欺骗性的不良行为。通过增强个体现在自 我与未来自我之间的心理联结程度可以增强被试 的未来自我连续性,降低其做出欺骗性行为的可 能性。Van Gelder 及他的团队(2015)采用互动任务 进一步验证了未来自我连续性与青少年不良行为 之间的关系。他们考察了两所中学中共 133 名高 中生,借助 Facebook 平台分别让学生与未来自我 或现在自我进行互动。结果发现:相比于与现在 自我交流的学生相比, 与未来自我交流的学生报 告了较少的不良行为,例如逃课和偷窃等。最后, 未来自我连续性还会影响人们的亲社会行为,现 有研究主要考察了与金钱有关的捐款行为,但是 目前有关未来自我连续性对捐款行为的影响作用 的研究结果并不一致。Zhang 和 Aggarwal (2015) 通过操纵被试的未来自我连续性发现:现在自我 与未来自我联结程度高的个体有更多的亲社会行 为,例如为公益组织捐款。而 Bartels, Kvaran 和 Nichols (2013)则发现与未来自我之间的心理联结 程度较低的被试有更多的亲社会行为,也更愿意 为慈善组织捐款。

#### 3.5 对健康领域的影响

未来自我连续性还可以影响与健康领域有关的行为。Rutchick等人(2018)新近的研究考察了未来自我连续性对个体锻炼行为的影响作用。他们首先通过相关研究揭示了未来自我连续性与个体自我报告的健康水平有关。然后通过具体的实验研究操纵未来自我连续性,他们采用书写任务让实验组的被试给20年的未来自我写信,并让被试完成一系列的日记记录任务,其中包括每天锻炼身体的时长。结果发现增强个体的未来自我连续性增加了被试锻炼身体的行为。这意味着未来自我连续性可以促进有益于个体长期健康的行为,对未来自我连续性进行干预具有重要的现实意义。

为了更清晰的展示上一章节中未来自我连续 性的操纵方法和本节中的行为研究结果,我们把 常见的操纵方式和相关的结果变量整理在表1中, 供感兴趣的研究者参阅。

#### 4 未来研究展望

#### 4.1 开展未来自我连续性的神经基础的探讨

现有研究指出皮质中线结构(cortical midline structures, CMS) 是自我加工的主要神经基础 (Northoff et al., 2006)。皮质中线结构主要指位于 大脑皮质中线的一些脑区结构,包括:腹内侧前 额叶皮质(ventral medial prefrontal cortex, vMPFC)、 背内侧前额叶皮质(dorsal medial prefrontal cortex, dMPFC)、顶内侧皮质(medial parietal cortex, MPC) 和压后皮质(retrosplenial cortex, RSC)等区域。而 有关时间维度上的自我加工同样涉及皮质中线结 构,特别是内侧前额叶皮质(medial prefrontal cortex, MPFC) (D'Argembeau et al., 2010; D'Argembeau et al., 2008; 杨帅, 黄希庭, 傅于玲, 2012)。D'Argembeau 等人(2010)采用自我参照任务考察被试对不同时 间维度上自我的加工。他们发现: 与判断过去的 自己与未来的自己相比, 内侧前额叶皮质在加工 现在自我时出现更为显著的激活,而右顶叶下回 皮质(right inferior parietal cortex)的激活程度在加 工未来自我时显著强于现在自我。那么皮质中线 结构应该也是未来自我连续性的神经基础。另外,

表 1 未来自我连续性的操纵及结果						
参考文献	操纵方式	关键结果	结果测量			
Bartels & Rips (2010)	<b>阅读任务</b> 实验组:阅读曲折变化的人物经历 控制组:阅读变化较少的人物经历	时间折扣	跨期决策任务			
Bartels & Urminsky (2011)	<b>阅读任务</b> 实验组:自我认同是不变的 控制组:自我认同随时间变化	时间折扣	跨期决策任务			
Hershfield et al. (2012)	<b>书写任务</b> 实验组:想象并描述现在自我与 10 年后的 未来自我之间的相似处 控制组:想象并描述 10 年后的世界	不道德行 为	自我报告不适当谈判策略量表 (Self- reported inappropriate negotiation strategies scale II,SINS II, Lewicki, Saunders, &Barry, 2007)			
Van Gelder et al. (2013)	<b>书写任务</b> 实验组:给 20 年后的自己写信 控制组:给 3 个月后的自己写信	社会不良 行为	情景想象任务			
Zhang & Aggarwal (2015)	<b>书写任务</b> 实验组:想象并描述现在自我与5年后的未 来自我之间的相似处 控制组:想象并描述未来自我与现在自我之 间的不同	亲社会行 为	为公益组织捐款			
Rutchick et al. (2018)	<b>书写任务</b> 实验组:给 20 年后的自己写信 控制组:给 3 个月后的自己写信	健康行为	日记记录的锻炼时长			
Hershfield et al. (2011)	<b>互动任务</b> 实验组:采用浸入式虚拟现实技术,让被试 与老年时的自己互动 控制组:与现在的自己互动	时间折扣 储蓄	时间折扣任务 (Kirby & Marakovic, 1996)			

实验组:在Facebook上与未来自我交流7天 行为 控住组:在 Facebook 上与现在自我交流7天 未来自我连续性高的个体与未来自我连续性低的 个体相比, 二者在特定的心理过程中, 例如进行 跨期决策时, 在神经基础上是否存在差异呢? 未

互动任务

实验组:跟随音频材料进行未来想象

控制组:跟随音频材料进行关注现在的冥想

来研究可对此进行探究。 此外,现有的认知神经研究不仅发现个体在 加工现在自我和未来自我的神经基础上存在差异, 还发现大脑在加工未来不同时间距离上的自我时 神经基础也存在差异。采用事件相关电位 (Event-Related Potential, ERP)技术的研究发现时 间距离会影响个体对未来自我的加工(Luo, Jackson, Wang, & Huang, 2013)。被试判断自我参 照任务中的特质词是否可以描述未来近距离的自 我(例如 1 个月后的自己)时, 消极的特质词比积 极的特质词诱发了更多的晚正电位成分(550 和

Blouin-Hudon & Pychyl (2016) 互动任务

Van Gelder et al. (2015)

800 ms之间); 而在判断是否可以描述未来远距离 的自我(例如 3 年后的自己)时, 消极特质词和积 极特质词之间没有这种差异。这表明个体有关未 来自我的负性情绪加工受到时间距离的影响。在 对未来自我连续性进行测量和操纵时也可能会涉 及到不同的时间距离,例如研究者通常会要求被 试去描述特定时间距离的未来自我(如5年后的自 我)与现在自我之间的联系。探究不同时间距离上 未来自我连续性的神经基础,可以帮助研究者更 好的理解未来自我连续性的内涵,并有助于探究 未来自我连续性影响个体心理和行为的潜在机制。

拖延的多维测量

(Haghbin' Multidimensional Measure of Procratination, MMoP)

自我报告的不良行为, 如逃学

拖延行为

社会不良

#### 4.2 进一步探索未来自我连续性的影响因素

新近的横断研究发现, 年龄是影响未来自我 连续性的重要因素(Rutt & Löckenhoff, 2016)。随 着年龄的增长,人们知觉到现在自我与未来自我之 间的一致性程度更高(Hart, Fegley, & Brengelman, 1993), 老年人倾向于将现在自我与未来自我看得 更为相似, 联系得也更为紧密(Rutt & Löckenhoff, 2016)。此外, Lewis Jr 和 Oyserman (2015)发现细 化个体感知时间的刻度可以影响其感知到的时间 的长短,并进一步影响个体感知到的未来自我连 续性的强度。与以"年"来描述未来自我相比,以 "天"来描述未来自我会让被试感知到更高的未来 自我连续性,从而提前为未来做准备,例如以 "天"来描述未来会使个体更早的为退休后的生活 进行储蓄。除了时间刻度,研究者发现操纵感知 到的力量也会影响个体的未来自我连续性(Joshi & Fast, 2013; Pietroni & Hughes, 2016)。例如, 让 被试想象自己有控制力的场景,或者是给被试分 配领导角色增强其感知到的力量感,均可以提高 被试的未来自我连续性。

未来研究可进一步探讨其他因素和未来自我 连续性的关系,例如文化有可能是影响未来自我 连续性的重要因素。大量的跨文化研究表明,人 们看待自我的方式受到其所处的文化背景的影响 (Kirmayer, 2007; Markus & Kitayama, 1991)。新近 一项在 33 个国家 55 个文化背景下开展的有关时 间维度上自我连续性的跨文化研究发现:人们对 过去自我、现在自我和未来自我的看法受到其对 个体身份认同的理解的影响。因为在有些文化下, 人们认为一个人的身份认同是随时间不断变化的, 而在另外一些文化下,人们却认为个体的身份认 同是不受时间影响的, 而认为个体身份认同不随 时间变化的个体倾向于将现在自我和未来自我看 得更为相似,从而报告更高的未来自我连续性。 此外,在不同文化背景下,人们看待其未来自我 的方式可能未必一致,未来自我连续性对个体心 理和行为的影响也可能不尽相同。

#### 4.3 拓展未来自我连续性的应用研究

虽然目前的研究已经揭示了未来自我连续性 对个体心理和行为的重要影响作用,但是目前的 研究大部分是基于实验室的研究,研究样本也多 是在校学生,有关未来自我连续性的具体应用研 究仍十分匮乏。例如,现有研究已经揭示未来自 我连续性对个体的储蓄和消费行为有重要的影响 作用(Hershfield et al., 2011)。未来研究可以考虑将 未来自我连续性的影响作用应用到个体理财的课 程或项目中,帮助人们减少冲动性消费行为,促进人们做出更多有益于未来自我的理财、投资和储蓄行为。此外,现有研究表明未来自我连续性高的人通常有更高的自控能力(Adelman et al., 2016)和较少的拖延倾向(Blouin-Hudon & Pychyl, 2016),对个体的学业成就领域有重要影响。研究者未来可以考虑在学校中大规模地对学生的未来自我连续性进行操纵,从而提高他们的自我控制能力、减少拖延行为,最终促进他们的学业成绩。

已有研究还发现未来自我连续性可以促进对 个体健康有益的锻炼行为(Rutchick et al., 2018), 但当前的研究只考察了被试的锻炼时长,采用的 指标也是个体自我报告的数据,将来研究可以采 用真实的锻炼或健身数据,进一步检验未来自我 连续性的影响作用。此外,未来自我连续性对个 体其他健康有关的行为应该也有影响,例如暴饮 暴食、抽烟、酗酒等不利于个体长远健康的行为。 未来研究应重点关注如何将未来自我连续性的影 响作用拓展到现实生活中,帮助个体调节其未来 自我连续性,以减少其不良行为,并促进有远见 的健康行为(比如积极锻炼、控制饮食等)。

总之,未来自我连续性作为自我领域一个新的研究前沿,正得到越来越多的重视。未来自我连续性对个体的跨期决策、储蓄和消费行为、学业成就领域、社会行为和健康领域等方面有着重要的影响作用。开展未来自我连续性神经基础的探讨,进一步探索其影响因素,从而拓展对未来自我连续性的研究具有重要的理论意义。了解未来自我连续性的研究具有重要的理论意义。了解未来自我连续性对个体心理和行为的重要影响作用,拓展相关的应用研究,并将未来自我连续性有利于个体决策行为、学业成就领域和健康等领域的影响拓展到人们实际的生活中具有重要的现实意义。

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#### The concept of future self-continuity and its effects

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**Abstract:** Future self-continuity refers to the degree of perceived connectedness between one's present self and future self. A large body of research has demonstrated the significant role of future self-continuity in influencing temporal decision making, saving and consuming behaviors, academic achievements, social behaviors and exercise behavior. Future research may examine the neural basis of future self-continuity, explore its factors, and expand its potential applications.

Key words: future self-continuity; intertemporal decision making; temporal discounting