# Chapter 6 The Promise and Pitfalls of Studying the Neurophysiological Correlates of Automatic Imitation



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Few areas of current research have shed as much light on human social cognition as studying the cognitive and neurophysiological mechanisms of human imitation. Be it copying the posture, body language, or accent of someone we like—our ability to imitate others has been argued to build social connection between people (for a review, see Chaps. 13 and 14; this volume). Indeed, many researchers suggest that copying behaviours are at the very heart of being human and may have contributed to our species' survival success (Henrich, 2015; Legare & Nielsen, 2015; Nagy & Molnar, 2004; Wood, 2020). While a simple conceptualisation of imitation as "monkey see, monkey do" implies copying as a simple motor act with no social consequences, it is now generally accepted that imitation is a much more complex and multi-dimensional phenomenon that serves important social functions across multiple species. We often think of imitation as intentional (such as when learning a new skill), but people also tend to copy others without their conscious awareness, a process referred to as "automatic imitation" (Heyes, 2011).

Automatic imitation has been argued to be an adaptive and flexible behaviour that is central to social cognition, which strengthens social bonds between interacting partners and thus provides a functional benefit that can help guide social interactions (Chartrand & van Baaren, 2009; Kavanagh & Winkielman, 2016; Wang & Hamilton, 2012). Given the ubiquitous influence of imitation on our daily lives, it is not surprising that researchers have studied automatic imitation across a range of interconnected disciplines including cognitive science, social psychology,

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evolutionary biology, and cognitive neuroscience (Byrne & Russon, 1998; Chartrand & Bargh, 1999; Meltzoff & Prinz, 2002). This convergence across multiple disciplines has allowed for a range of perspectives on imitation to emerge, further empowered by neuroimaging advances in the last two decades.

Across these research domains, a variety of methods that vary in ecological validity have been adopted to index automatic imitation and its underlying cognitive and neural mechanisms. These methods include observation of live social interactions, as well as reaction-time measures based on stimulus-response compatibility (SRC) paradigms (Brass et al., 2000; Chartrand & Lakin, 2013). However, as in any domain of psychological research, drawing links between real-world behaviours, such as imitation, and laboratory-based measurements is fundamentally challenging and requires considerable validation for it to be meaningful (Ramsey, 2018; Scheel et al., 2021; Vazire et al., 2022).

Much like psychological research in general (Vazire et al., 2022), concerns about validity (i.e., whether the research study measures what it intends to measure) in the field of automatic imitation have not been at the forefront of the research programme until recently (Cracco & Brass, 2019; Ramsey, 2018). For example, tasks that index so-called "automatic imitation" are routinely used that claim to be "social" in the sense that they index cognitive processes that are specifically tied to the control of social interactions (Brass et al., 2009; de Guzman et al., 2016; Sowden & Shah, 2014; Steinbeis, 2016; Wang & Hamilton, 2012). However, such claims are substantially undercut by a lack of evidence for important dimensions of validity (Ramsey, 2018; but see Cracco & Brass, 2019 for a different view).

In the current chapter, therefore, we outline the promise and pitfalls of studying the neurophysiological correlates of automatic imitation. First, we consider the promise that this field has to offer by reviewing recent evidence across disciplines on the cognitive and neurophysiological mechanisms underlying automatic imitation. Second, we consider the pitfalls of this field by evaluating the evidence in the context of four types of validity: construct validity, internal validity, external validity, and statistical-conclusion validity (Shadish et al., 2002; Vazire et al., 2022). The conclusion we reach is that there is much promise to taking a cognitive neuroscience approach to studying automatic imitation, as it holds the potential to study key mechanisms of social cognition. However, there are also considerable pitfalls, which include a lack of validity for some of the claims being made. The good news is that there are many avenues for future research that could lead to a more robust and cumulative science of automatic imitation that would help the field realise its considerable potential, and we outline these future research directions throughout the chapter.

Our approach is to focus on one particular task, which has been influential and widely used in cognitive neuroscience research on imitation due to its ease of use in a wide variety of contexts, including neuroscientific investigation. We think it is valuable to provide a detailed test-case of the types of claims being made regarding the neurophysiological correlates of imitation, rather than provide a more comprehensive overview, as others have already done so (Heyes & Catmur, 2022; Iacoboni, 2009). At the same time, we recognise that there are many forms and types of

imitation, such as imitation of speech, gestures, and emotions, some of which are covered in other chapters within this book. Importantly, however, many of the themes covered in this chapter, such as a lack of evidence for validity, are wide-spread and well-documented across psychological science in general (Vazire et al., 2022). Therefore, the conclusions from this chapter are likely to be applicable to the many other forms of imitation covered in this book, as well as the wider social and cognitive neuroscience community.

# The Promise: Automatic imitation as a Window into Understanding Mechanisms of Social Cognition

In social psychology, automatic imitation, also termed as mimicry, has been studied in naturalistic social interactions (Chartrand & Bargh, 1999; Chartrand & Lakin, 2013). These paradigms involve recording overt copying behaviours. In contrast, in cognitive psychology and cognitive neuroscience, SRC tasks of automatic imitation have been argued to measure covert processes involved in controlling our tendency to automatically imitate using reaction time (RT) measures or kinematics (Heyes, 2011; for a review on different behavioural tasks to measure automatic imitation, see Chap. 2, this volume). In automatic imitation research, the first SRC paradigms indexing automatic imitation were developed by Brass et al. (2000) and Stuermer and colleagues (2000) using finger and hand stimuli, respectively. Since then, different versions of the initially developed SRC paradigms have been widely used in order to index imitative processes, and involve finger movements (Bertenthal et al., 2006; Brass et al., 2000; Catmur & Heyes, 2011), hand opening/closing movements (Heyes et al., 2005; Press et al., 2008), or arm movements in vertical or horizontal planes (Kilner et al., 2003; Stanley et al., 2007).

In a typical SRC task indexing automatic imitation, participants are instructed to respond to an imperative cue while also viewing an action on screen that is either compatible or incompatible to their own response. For example, participants may be instructed to lift their index finger when they see a number "1" on the screen and lift their middle finger when they see a number "2" on the screen. Simultaneously, they either view an index or middle finger movement on the screen. In compatible trials, the movement they see and execute are the same, whereas in incompatible trials the movement they see and execute are different. Results from these experiments consistently show that features irrelevant to the task (the index and middle finger movements that participants view) influence reaction time performance. Participant reaction times are longer in the incompatible condition compared to the compatible condition, and this reaction time difference has been argued to be a measure of imitation control (Heyes et al., 2005; Heyes, 2011).

As with other SRC measures using reaction times, SRC measures of automatic imitation are typically far removed from imitative behaviour "in-the-wild" and involve computerised testing procedures in laboratory settings, which provide a higher degree of experimental control. These tasks, therefore, lend themselves well to neuroimaging investigations where movement is restricted such as in functional magnetic resonance imaging (fMRI) studies. Neurophysiological investigations across social and cognitive neuroscience on automatic imitation have therefore mostly used different versions of the SRC task to index the control of automatic imitation and its underlying neural mechanisms (Bien et al., 2009; Brass et al., 2009; Darda et al., 2018).

At least two processes are involved during compatible and incompatible trials on the SRC task: action representation and action control or selection (Ramsey, 2018). First, observed actions in both compatible and incompatible conditions are perceived and represented. Second, a particular action needs to be selected and executed, dependent on the task instructions. Task demands on compatible and incompatible trials are different—on compatible trials, the action control or selection mechanism is assisted by observing the same action that needs to be executed, whereas on incompatible trials, action selection is challenging as it requires an additional effort to inhibit the observed action and execute the correct one. Consequently, it has been argued that the difference between incompatible and compatible trials, termed the compatibility effect, partly indexes control over our tendency to automatically imitate, such that incompatible actions are suppressed and one's motor intentions are prioritised (Brass & Heyes, 2005; Heyes, 2011).

A related interpretation suggests that the compatibility effect indexes a process of self-other distinction wherein motor intentions of one's own actions need to be distinguished from the motor intentions of another's actions (Brass et al., 2009). According to this interpretation, the control of imitative behaviour as indexed by the compatibility effect can also be considered as a measure of online control of self-other representations (Brass & Heyes, 2005; Santiesteban et al., 2012). A self-other distinction mechanism is thought to be a key process underlying many other socio-cognitive processes including empathy and our ability to attribute mental states to ourselves and others (de Guzman et al., 2016; Sowden & Shah, 2014; Steinbeis, 2016).

Several human neuroimaging and patient studies have investigated the underlying neural mechanisms of representation and control in the context of automatic imitation (Fig. 6.1). Representation of actions is likely to involve both perceptual and motor representations. For example, visual perception of others in our environment involves person perception processes such as the representation of faces, bodies, and biological motion that span the ventral visual stream and occipitotemporal cortices (for a review, see Kanwisher, 2010), as well as brain regions associated with motor performance in dorsolateral frontoparietal cortex (Bonini et al., 2023; Caspers et al., 2010; Cross et al., 2009, 2012; Hardwick et al., 2018; Iacoboni, 2009; Molenberghs et al., 2012; Rizzolatti & Craighero, 2004). Such findings are robust in the sense that they have been demonstrated in hundreds of experiments and across thousands of participants, as well as in meta-analyses, and across different methods and species (Bonini et al. 2023; Caspers et al., 2010; Kanwisher, 2010; Hardwick et al., 2018).

One dominant view is that a sub-part of the action representation system, which spans frontoparietal cortex and has been labelled the mirror neuron system, is



**Fig. 6.1** Graphical illustration of action perception and representation, and a domain-specific (theory-of-mind network) and domain-general (multiple demand network) account of action control and selection in the context of automatic imitation. (Fig. 6.1 is taken from Darda & Ramsey, 2019)

involved in imitation (Heyes & Catmur, 2022; Iacoboni, 2009; Rizzolatti et al., 2001). The mirror neuron system is defined by cells (or macroscopic brain areas) that respond to the observation, as well as the execution, of action (Rizzolatti & Craighero, 2004). Given such neurophysiological properties and that imitation is defined by observing and performing actions, it seems intuitive that such a system would be involved in imitation in some way. However, we do not think it is intrinsically interesting that such cells exist or that they play some role in imitation. We think it could be interesting if studies were able to show what these particular cells do during imitative contexts, but that is very hard in human participants because of the reliance on non-invasive neuroscientific techniques that have poor spatial resolution relative to single-cell recordings. Nonetheless, for the purposes of this chapter, the main point to underscore here is that it seems highly likely that such a visuomotor action representation system plays some role in imitation as part of a distributed and multi-system neural network (Heyes & Catmur, 2022).

In contrast, the neurophysiological mechanisms underlying the control and selection of actions in the context of automatic imitation are less clear. In the following section, we outline two proposed accounts of control and selection in the context of imitation, which make divergent predictions: (1) Domain-specific control that relies on the theory-of-mind (ToM) network and a process of self-other distinction, and (2) Domain-general control, which relies on the multiple-demand network and general mechanisms of attention.

The first account, which is dominant in the literature, proposes that action control and selection in the context of automatic imitation rely on a domain-specific brain circuit related to social cognition and a mechanism of self-other distinction (Brass et al., 2009). The initial evidence supporting a domain-specific neural circuit underlying this process comes mainly from patient and neuroimaging studies, and points to the engagement of two candidate brain regions-the anterior medial prefrontal cortex (mPFC) and the right temporoparietal junction (rTPJ) (Brass et al., 2001, 2009; Brass & Heyes, 2005; Spengler et al., 2009). mPFC and rTPJ have been consistently identified as key nodes in the theory-of-mind (ToM) network, which is a brain network that is engaged in a wide range of social cognition tasks (Frith & Frith, 2010, 2012; Van Overwalle, 2009). Furthermore, there is a proposed functional dissociation between mPFC and rTPJ. The rTPJ is thought to differentiate between the self and the other, whereas the mPFC selects and enforces the correct action according to task demands (Brass et al., 2009). The functional division between mPFC and rTPJ is consistent with the interpretation that this particular compatibility effect indexes a process of self-other distinction.

The involvement of mPFC and rTPJ has been further supported by studies that demonstrated that patients with focal lesions show impaired imitation control (Brass et al., 2003; Spengler et al., 2010). Similarly, inhibiting rTPJ activity by transcranial magnetic stimulation (TMS) further impaired imitation control (Sowden & Catmur, 2015), whereas the impact of transcranial direct current stimulation on rTPJ was less clear (Hogeveen et al., 2015). More generally, mPFC and rTPJ have also been found to be engaged in other socio-cognitive tasks that are thought to rely on self-other control, including empathy, perspective taking, and attributing beliefs, desires, and attitudes to oneself and others (Frith & Frith, 2010, 2012; van Overwalle, 2009). Therefore, it is argued that the engagement of mPFC and rTPJ in this SRC task reflects the function of a neural network that is central to social cognition—the ToM network—and which is specifically engaged in regulating social interactions with other people (Brass et al., 2009; Sowden & Shah, 2014; de Guzman et al., 2016; Steinbeis, 2016; Wang & Hamilton, 2012).

A second account suggests that action selection and control in the context of automatic imitation may rely on a more domain-general neural circuit that is not specific to social contexts. That is, the control and selection mechanisms involved in SRC tasks with human action stimuli may not differ from mechanisms of control that are involved in resolving conflict in any other SRC task with pre-potent tendencies (Ramsey & Ward, 2020b). Cognitive control tasks such as the Stroop, Simon, and Flanker tasks require the control of automatic and overlearned response tendencies as well, similar to the SRC measure of automatic imitation, and these tasks have been found to engage dorsolateral frontoparietal cortices (Aron et al., 2014; Bunge et al., 2002; Nee et al., 2007; Wager et al., 2005).

This domain-general network that spans dorsolateral frontoparietal cortices has been labelled the multiple demand (MD) network because it is engaged across multiple mental operations that are deployed across a diverse range of stimuli and contexts (Duncan, 2010). For example, the same set of frontal and parietal brain regions were involved across 7 different, cognitively demanding tasks, which spanned a range of processes (reading, arithmetic, working memory, inhibition, and selection) and stimuli, such as words, numbers, colours, and spatial locations (Fedorenko et al., 2013). To further contextualise this brain system, the MD network shares functional and structural overlap with the frontoparietal brain circuit that is involved in a range of domain-general executive functions including processes such as filtering, selection, and inhibition, which can be applied to a range of inputs, both social and non-social (Corbetta et al., 2008; Petersen & Posner, 2012; Ptak, 2012).

In line with this domain-general account, some studies investigating the control of automatic imitation show engagement of the MD network (Bien et al., 2009; Crescentini et al., 2011; Cross et al., 2013; Darda et al., 2018; Marsh et al., 2016; Mengotti et al., 2012). For example, using fMRI, Darda et al. (2018) first identified MD and ToM brain areas with independent functional localiser scans. They then showed that there were no effects of compatibility in ToM regions, even though it was a high-power, multi-experiment study that involved 75+ participants. In contrast, there were clear and obvious compatibility effects in the MD network. This result is important because while the MD network was robustly engaged, there was not even suggestive evidence for the engagement of the ToM network, which overturns the original research that used considerably smaller sample sizes (e.g., Brass et al., 2001, 2009). Moreover, in a meta-analysis of all fMRI studies investigating automatic imitation using the SRC task, Darda and Ramsey (2019) found engagement of regions associated with the domain-general MD network for the imitative compatibility effect, but not mPFC or rTPJ (Darda & Ramsey, 2019). Together, these more recent and methodologically rigorous fMRI results suggest that the SRC effect using finger stimuli reflects a domain-general process of control and action selection rather than one tied to operations within the ToM network.

In summary, in both accounts of action control and selection in the context of automatic imitation, the visual input to the control or selection system is the same, i.e., the observed person and action. Moreover, the evidence identifying the neural circuits involved in person and action representation have been consistently reported in many studies. The neural circuits involved in person and action perception span the ventral visual stream, as well as lateral frontoparietal cortex (Caspers et al., 2010; Hardwick et al., 2018; Kanwisher, 2010). However, evidence from cognitive neuroscience regarding the selection or control mechanism that underlies the inhibition or control of automatic imitative tendencies is much more mixed. Initial evidence suggested the mechanisms might be domain-specific but later evidence has more strongly favoured a domain-general viewpoint. Of course, in principle, it could involve a combination of both types of control systems.

These mixed findings, especially the relatively weak evidence for domainspecific or "social" forms of control, raise questions about the validity of the claims being made. Based on decades of research studying cognitive control in similar SRC tasks, which do *not* have social dimensions (Duncan, 2010; Petersen & Posner, 2012), it would be quite striking if control and selection in the SRC imitation task requires such a departure from a standard "non-social" control model of executive function. In our view and the view of many others, such a departure from conventional models would require clear validation to empirically substantiate the novel claims being made (Flake & Fried, 2020; Ramsey, 2018; Ramsey & Ward, 2020b; Vazire et al., 2022). The novel claim being made by domain-specific, "social" control accounts is that this task indexes cognitive control processes that are specifically and uniquely tied to controlling interactions with other people and underpinned through the operation of the ToM network and a self-other distinction mechanism. Although this is plausible in principle, it needs empirical validation to be meaningful. To this end, in the next section, we evaluate the SRC automatic imitation task across a range of different types of validity.

# The Pitfalls: A Lack of Validity Undercuts Some of the Specific Claims Being Made Regarding the Cognitive Mechanisms Underlying Automatic Imitation

Irrespective of the cognitive interpretation placed on the compatibility effect, and the underlying neural systems that are proposed to be engaged, almost all studies use the SRC paradigm as an index of automatic imitation. If the SRC paradigm is a laboratory equivalent of overt copying behaviours, as has been suggested (Heyes, 2011), the validity of the SRC task is a crucial component when evaluating evidence for domain-specificity for the control of automatic imitation.

Before turning to consider validity in more depth, however, we will quickly consider the reliability of the SRC measure of automatic imitation. Interference effects using hand or finger stimuli and an SRC paradigm appear to be reliably generated (Genschow et al., 2017). Genschow et al. (2017) used a split-half reliability approach to show that the congruency effect had high levels of reliability (Spearman-Brown coefficient  $\rho^* = 0.86$  for the congruency effect). Also, Cracco and colleagues (2018a) performed a meta-analysis, which showed robust SRC effects across a range of labs, stimuli, and participants. Therefore, these results are promising, as reliable measures that replicate across samples are essential features of good measurement tools.

At this juncture, we want to make an obvious point: measures can be reliable without also being valid. For example, the SRC task with hand or finger stimuli could reliably generate an interference to reaction time *without* indexing covert imitative response tendencies, which are uniquely tied to social interactions and rely on a self-other distinction mechanism, as well as the ToM network. It is something very different to demonstrate with empirical evidence that a reaction time cost indexes covert imitative response tendencies, rather than some more general conflict resolution system. As such, in the following sub-sections, we now consider current evidence regarding the SRC automatic imitation task against four different types of validity outlined by Vazire et al. (2022) that span construct, internal, external, and statistical-conclusion validities. Whenever relevant, we also outline possible avenues for future research.

Before we do so, however, we also want to clarify the claim we are evaluating here. In the below analysis of validity, we focus on the conjoint claim that the congruency effect in this task indexes imitative tendencies and is resolved by a selfother mechanism that is underpinned by the ToM. This is because that is the claim that has been made and re-used by many other researchers to somehow verify (or reify) that this task indexes "social" processes in some way, rather than indexing general cognitive control mechanisms. It is also because this claim is, in part, based on neuroscientific evidence and this is a chapter about the neurophysiological correlates of imitation.

#### Construct Validity

Construct validity refers to the degree to which inferences about the construct of interest can be appropriately made from measured or manipulated measures. Simply put, it refers to the extent to which a test or variable measures what it is supposed to measure, and whether an experimental manipulation manipulates what it is supposed to manipulate (Cronbach & Meehl, 1955; Vazire et al., 2022; Wilson et al., 2010). Does the SRC measure of automatic imitation measure the construct it is meant to represent?

Like other behavioural assessments of cognitive or social processes, such as the dot-probe task (Parsons et al., 2019) or the reading the mind in the eyes task (Higgins et al., 2022, 2023), most researchers use the SRC measure of automatic imitation without reporting reliability metrics and without clear evidence of validity. This common practice is problematic because defining constructs and establishing the construct validity of measures is essential for valid inferences to be drawn about the cognitive and neural underpinnings of these constructs (Bringmann et al., 2022; Flake & Fried, 2020; Scheel et al., 2021). Moreover, such concerns are not restricted to cross-sectional research that use self-report measures, as they also apply to experimental designs that manipulate variables (Chambers & Tzavella, 2022; Chester & Lasko, 2021; Ejelöv & Luke, 2020; Fiedler et al., 2021; Gruijters, 2022).

To date, only one peer-reviewed study that we know of has attempted to provide evidence of construct validity for the SRC measure of automatic imitation. If the SRC measure of automatic imitation is related to overt imitative behaviours, evidence that the compatibility effect is correlated with overt copying behaviours can provide one measure of construct validity. However, a study by Genschow et al. (2017) addressing the reliability and validity of the SRC measure of imitation control found that overt copying behaviours did not correlate with the compatibility effect on the SRC task. Therefore, the relationship between imitation control as measured by the SRC task and imitation in real life seems to be more complex than has been previously suggested. Moreover, the measure of overt copying was found to be unreliable using a split-half test of reliability, which throws further caution on using demonstrably poor measurement tools to validate other tools. Subsequent work, which has just been published, has followed this up by re-analysing an existing dataset that used a different design (Cracco et al., 2024). However, this work remains exploratory and only permits suggestive inferences, as it lacks large scale replications where the relevant analysis plan is pre-registered in advance and where the experiments use well-justified and a priori sample size planning. In short, much more work is needed, in terms of defining and evidencing the construct that the SRC task is trying to tap into, before clear and obvious inferences can be drawn about the underlying neural systems that may support performance on this task.

#### Internal Validity

Internal validity refers to whether a causal relationship exists between the findings and manipulated variables that cannot be explained by other factors (McDermott, 2011). That is, internal validity is the validity of causal inferences and is dependent on whether alternative explanations are convincingly ruled out, and assumptions on which causal inferences are made are adequately justified (Vazire et al., 2022).

As previously stated, it has been claimed that the SRC imitation task relies on a self-other distinction mechanism that engages the ToM network (including anterior mPFC and rTPJ) and is uniquely tied to regulating social interactions with others by controlling imitative tendencies (Brass et al., 2009; Sowden & Shah, 2014; Spengler et al., 2009; Wang & Hamilton, 2012). Are there plausible alternative explanations that undermine this claim? Yes. Have plausible alternative explanations been convincingly ruled out? No. We detail a few of these alternatives below.

The first and most obvious alternative explanation that has *not* been convincingly ruled out is that control processes in this task are domain-general in nature. Much like other tasks that require executive functions, this task requires the inhibition of pre-potent responses, along with the selection and prioritisation of alternative responses (Duncan, 2010; Petersen & Posner, 2012; Ptak, 2012). As we have previously outlined in some detail, we see no reason why this task could not also rely on such a domain-general control architecture (Ramsey, 2018; Ramsey & Ward, 2020b). In fact, the most comprehensive fMRI work to date suggests that the control processes in this task are domain-general and not domain-specific (Darda et al., 2018; Darda & Ramsey, 2019). This means that not only has a compelling alterative explanation not been ruled out, but a growing body of evidence also suggests that it is highly likely to be involved.

Further evidence for a domain-general account has emerged using an empirical and computational modelling approach (Hemed et al., 2022). Hemed et al. (2022) found that automatic imitation occurs only when the others' actions are in the current response set, and not for otherwise familiar but task-irrelevant actions. The authors suggest that like other "automatic" processes such as perception or implicit learning, automatic imitation can be unintentionally "controlled". Thus, the task at best measures *conditional* imitation control and might reflect general S-R compatibility effects rather than mimicry or overt copying behaviours per se.

One way to make more progress establishing internal validity in the future would be to first use methods that aid theory development and require researchers to be more formal and explicit about the way parts of a system are thought to relate to each, such as by building computational models (Hintzman, 1991; Smaldino, 2017; Yarkoni, 2022) and causal graphs (Pearl, 1995, 2018). For example, mathematical formulations would make it easier to falsify and disagree with each other by making explicit the specific predictions that different accounts make, which would aid in the development of more mature theories (Nosek et al., 2022). We agree with others that there is currently too much wriggle room with verbally specified theories in general in psychology (Yarkoni, 2022), and specifically in relation to SRC measures of automatic imitation, which restricts more precise theory development.

We, therefore, very much welcome the few computational models that have been put forward to account for effects observed within this automatic imitation task (Cooper et al., 2013; Cracco & Cooper, 2019) or how the task is influenced by motor training (Cooper et al., 2013). However, like many other areas of psychology and human neuroscience research, we feel that the role of computational models needs expanding, in order to develop more mature theories (Proulx & Morey, 2021; Nosek et al., 2022). For example, and of particular relevance to this chapter, our lab has recently built a working computational model that clearly shows how the task could be solved by largely domain-general control and selection processes (Ward & Ramsey, 2024). If anyone is curious about the details of the computational model, then download it and run the model yourself, as it is freely available online and runs in the R programming language.

To give a further concrete example of how computational models can help clarify debate and organise future research, we consider evidence for "top-down modulation" of the SRC task by social factors (Ramsey & Ward, 2020a). Some authors seem to imply that if other social factors impact the size of the SRC effect, then it suggests that the cognitive processes involved in the task are "social" or "imitative" in some sense. In terms of empirical evidence, findings are mixed for this claim, with some studies showing modulation (Chiavarino et al., 2013; Cracco et al., 2018b; Genschow & Schindler, 2016) and others not (Galang & Obhi, 2020; Genschow et al., 2022; Rauchbauer et al., 2020).

In principle, however, we do not find this kind of argument at all convincing because the task itself lacks internal validity. That is, it seems to ignore the obvious, which is that social factors can impact mechanisms of attention (of which there are many), rather than anything specifically tied to imitation, and this could influence the size of the interference effect. Therefore, even if robust evidence emerges that some social factors can modulate the SRC task, without sufficient evidence for the internal validity of the task, it remains completely unknown and unproven if such modulation to interference reflects an impact on domain-general aspects of attention. As such, there is a very large evidence-based alternative explanation, which looms in the background and needs to be tackled head-on rather than avoided. And we think computational modelling can play a useful role in helping to elucidate the predictions that follow from different accounts of the underlying cognitive

processes involved. In other words, computational models and causal graphs provide a more formal way to specify your hypotheses and assumptions, which can in turn be interrogated by others.

# External Validity

External validity refers to whether observed effects are generalisable beyond the specific context of the study (Vazire et al., 2022). Can a given set of findings apply to a broader context?

As demonstrated in a recent meta-analysis, the SRC task of automatic imitation has been widely used across different samples, contexts, and stimulus groups (Cracco et al., 2018a). Therefore, the general compatibility effect as measured with reaction times appears to be quite robust in that it generalises across different sample characteristics and stimuli. However, the general compatibility effect that was measured in the majority of studies in the meta-analysis by Cracco, Bardi, and colleagues (2018a) is confounded by spatial effects. Indeed, only 54 out of 205 studies independently separated spatial from imitative effects. For instance, it is common for the observed hand to be a left hand and for participants to respond with their right hand. This experimental setup means that in compatible conditions, the observed finger is the same as the one that participants use (i.e., imitatively compatible), but the finger is also on the same side of space (i.e., spatially compatible).

An imitative compatibility effect that does not have the spatial confound can be measured by presenting both right and left hands to the participants (Catmur & Heyes, 2011), and calculating an effect of incompatible finger identity (rather than an incompatible spatial location). However, this so-called "imitative" effect is considerably smaller than the general compatibility effect, and more variable in the direction of the effect across people such that many individual participants show a negative imitative compatibility effect (Fig. 6.2). A negative compatibility effect shows that incompatible conditions facilitate, rather than interfere, with reaction times. So, even though the group average effect may consistently be above zero, a substantial minority of participants (approx. 25%) show the opposite of an imitative compatibility effect (compared to approx. 4% of participants who show the opposite of a spatial compatibility effect). Whilst we appreciate that the general approach in experimental psychology is to largely focus on group average effects (rather than individual differences), it does seem curious to us that if automatic imitation is so central to social life and this SRC task provides a signature of that process, then why do so many individuals not show an imitative effect? We feel that this would be worthy of addressing in future research.

Across psychology and cognitive neuroscience research more broadly, the generalisability of findings has also been questioned. For example, recent studies suggest that more than 50% of neuroimaging findings are likely to be false positives, and more than 40% of study findings do not replicate due to problems with small sample sizes, statistical power, p-hacking, and publication bias, as



Fig. 6.2 Imitative and spatial compatibility effects as measured by reaction time. Error bars indicate standard deviation. The figure is based on data from Darda et al. (2020), Experiment 3, with N = 189 participants. (The data can be found on the Open Science Framework repository: https://osf.io/fsh9b/)

well as a lack of data sharing (Button et al., 2013; Hong et al., 2019; Munafò et al., 2017; Szucs & Ioannidis, 2017).

The generalisability and replicability of human neuroscience findings in the field of automatic imitation are also likely to be compromised given the low sample sizes of the original work and lack of pre-registered replication studies. The initial patient, fMRI, and neurostimulation studies, which are considered seminal in the field, have been used to evidence a role for the ToM network (mPFC and rTPJ) in controlling imitative tendencies (Brass et al., 2009; Spengler et al., 2009; Santiesteban et al., 2012). However, until pre-registered replication studies have been performed that use well-justified sample sizes and statistical approaches, we should remain very cautious about these results, given the wider landscape of irreproducible research and questionable research practices that plagues psychology and human neuroscience research in general (Munafò et al., 2017; Nosek et al., 2022; Simmons et al., 2018). As such, just like any other aspect of science, it is essential that modest claims are drawn before the reliability, validity, and generalisability of measures and findings can be evidenced (Ramsey, 2021).

Moreover, to our knowledge, neuroimaging studies of this SRC automatic imitation task have almost exclusively focused on Western populations, which means that one way of increasing external validity would be to generalise the findings across different populations underrepresented in research samples (Henrich et al., 2010). Once more evidence for the basic validity of the task is established, it would then be interesting to see which components, if any, vary as a function of cultural background. If the task is shown to index domain-specific and domain-general forms of control, then it would be interesting to see if either of these vary across cultures. For example, maybe more "individualistic" cultures might show reduced interference compared to cultures known to be "collectivist", as has been evidenced in other socio-cognitive processes such as self-recognition and social orientation (Sui et al., 2009; Varnum et al., 2010). Such a proposal is speculative at the moment, however, and would necessarily require evidence for the validity of the basic task first.

#### Statistical-conclusion validity

Statistical-conclusion validity is the validity of statistical inferences. Due to low sample sizes (e.g., <20) and noisy signals, early fMRI work in general has been demonstrably proven to show poor statistical-conclusion validity (Cremers et al., 2017). This likely explains why the initial fMRI evidence using the SRC task (Brass et al., 2001) could not be replicated when it was submitted to a much more rigorous test using larger sample sizes with higher statistical power, multiple experiments, and functional localisers (Darda et al., 2018). The original work had 10 participants and used a fixed-effects analysis, which makes it hard to generalise beyond the data itself (Brass et al., 2001). It also makes chance variation and sampling error more likely.

The same lack of evidence for statistical-conclusion validity also applies to the patient and neurostimulation research using this task (Brass et al., 2003; Spengler et al., 2010; Hogeveen et al., 2015; Sowden & Catmur, 2015). Such work has been used to provide so-called "causal" evidence for the domain-specific, "social" control hypothesis. Like the fMRI work using this SRC task, the claims in these studies are based on one-off experiments with relatively small sample sizes. Pre-registered, larger-scale replication studies have not been completed to date. This is important to highlight because neurostimulation research, for example, has well-documented difficulties reproducing past findings, as well as the use of questionable research practices (Héroux et al., 2015; Jalali et al., 2017; Medina & Cason, 2017).

We want to make something clear here: we are not being critical of the sample sizes used in fMRI, patient or TMS studies in the late 1990s or early 2000s, as it was consistent with the industry standard of the time. We also do not want to deny that when technological innovations occur, which tend to be expensive, it might not be feasible to run studies that collect an optimal amount of data. We are firm believers that when such opportunities for novel research directions come along, researchers should not be afraid to be creative and pursue novel collaborations and exploit new techniques and methods. However, we do think that far too much emphasis was placed on these early results before the requisite confirmatory research was completed. It would have been extremely valuable to show in comprehensive follow-up research that these initial findings were robust and that the measurement tools were

reliable and licensed valid inferences. As such, we think that researchers should adopt a more cautious attitude to science, especially when evaluating novel findings (Ramsey, 2021).

In the future, we see this as a good opportunity to embrace meta-science and open science best-practices (Munafo et al., 2017), as well as the routine completion of much more preparatory groundwork before moving towards a confirmatory "test" of a hypothesis (Scheel et al., 2021). For example, researchers can pre-register the main question and specific analysis pipeline to reduce "p-hacking" and weak statistical inferences. Furthermore, making the data available (even large fMRI datasets) would allow others to use it to guide future research plans, as well as perform alternative analyses and meta-analyses. There are plenty of resources available for making data available and for using externally validated processing scripts (Esteban et al., 2019; Poldrack & Gorgolewski, 2014, 2017; Yarkoni et al., 2011).

#### **Summary and Implications**

We have reviewed cognitive neuroscience claims associated with the SRC automatic imitation task across four different types of validity. We find that it lacks clear and comprehensive evidence for each kind of validity. Of course, this does not mean that the SRC task does not measure imitation control at all, or that imitation does not rely on a self-other distinction mechanism. It just means that such claims are currently unproven. It might be measuring one component of a more complex and multi-component process of imitation (Genschow et al., 2017), which we currently do not understand well. However, it might also only reflect domain-general cognitive control mechanisms that are applied to social stimuli (hands, fingers). The current state of the evidence suggests that alternative domain-general interpretations exist and are well-evidenced. In contrast, when subjected to a more methodologically rigorous test, there was not even suggestive evidence that the ToM network (mPFC and rTPJ) was engaged during imitation control (Darda et al., 2018; Darda & Ramsey, 2019). Therefore, until solid evidence for the validity of the SRC task can be established, and credible alternative explanations ruled out, we suggest that the task should not be used as an index of self-other distinction that is uniquely tied to social interactions through the control of imitation.

If the task lacks evidence of validity, why do researchers keep using it? We understand why many researchers would not want to discard this laboratory task. It has many appealing practical advantages. It is quick and easy to administer, and it reliably demonstrates an interference effect, which some say can address questions in social cognition. Therefore, it is appealing. And there may not be any reason to discard it, if it can be used in such a manner that it licenses empirically justifiable and valid claims. To put this in a wider context, validity is lacking from many paradigms, not just this one (Vazire et al., 2022). So, this reflects a more general problem that extends well beyond this task alone, which should not be ignored, otherwise we

will spend another 20 years or more doing research with paradigms that lack conventional evidence for the validity of the underlying claims.

A further reason why the task has been widely used despite a lack of validity is that publishing, grant allocation, and hiring incentives are not aligned with first doing "boring but necessary" work (Scheel et al., 2021). Therefore, a research culture has developed that has downplayed or completely ignored the importance of good measurement (Flake & Fried, 2020). If it is simply not necessary to do this kind of work before you publish it in mainstream journals, why bother doing it?

A final reason is that some researchers argue that the SRC task already has sufficient evidence of internal validity to make claims that are specifically tied to automatic imitative tendencies (Cracco & Brass, 2019). Consequently, it has been suggested that there is no need to provide further empirical validation for the SRC automatic imitation task against the conventional types of validity outlined above (Cracco & Brass, 2019). Instead, Cracco & Brass (2019) suggest that measuring reaction time interference in an experimental task that involves observing and responding with the same or different body part is already sufficient evidence to validate the claims being made regarding automatic imitative tendencies. We (and many others) disagree and suggest that measurement quality is at the very heart of good science, which makes providing comprehensive evidence of the validity of measurement tools an essential component in making meaningful inferences from data (Chester & Lakso, 2021; Fiedler et al., 2021; Flake & Fried, 2020; Scheel et al., 2021). Moreover, we have so far seen no special reasons why this same logic of good measurement and validation should not be applied to the SRC automatic imitation task, or any other measure of imitation for that matter.

The minimalist validity position taken by Cracco and Brass (2019) leaves open the very real possibility that social stimuli (fingers, hands, etc.) could be driving a response conflict that is resolved by a domain-general response conflict system. Therefore, using this type of SRC task could be probing the operations of a domaingeneral response conflict system, just with social stimuli. As such, based on the evidence reviewed here, there seems to be a misalignment between the current empirical validation of the experimental design and the inference about the nature of cognitive systems being tested. To go beyond this position and make a more specific claim about the type of control being measured here, one that is *not* domaingeneral, would need clear validation, just like any other task or measure in any other aspect of psychology (Vazire et al., 2022).

If researchers want to proceed with using the SRC task without first establishing evidence for the types of validity that we have reviewed in this chapter, then the inferences drawn should be calibrated appropriately. That is, we feel it is no longer tenable to claim that the SRC task indexes automatic imitative tendencies that tap into a process of self-other distinction, which relies on the ToM network. Instead, the burden of proof is on researchers making these claims when using these tasks to provide the relevant evidence that validates their inferences. As with any task, however, in principle there are multiple ways that they can be used and many purposes that they may serve, which means it could still be valuable for addressing a range of research questions. For example, it might be informative to study domain-general cognition in this way, but it would need to be explicitly stated how. What are the theoretical and empirical contributions being made with such a paradigm? For the reasons outlined in this chapter, however, we do not see how that the task can be used to make claims about processes that are uniquely tied to regulating social interactions.

## Limitations and Constraints on Generality

We have intentionally chosen to focus on one specific type of task here. Therefore, by definition, our analysis does not directly extend to all possible types of imitation tasks. However, although we use one task to provide a thorough test-case example, we think that a lack of evidence for validity has a high likelihood of being applicable to other imitation tasks, given the widespread validity issues in psychology (Vazire et al., 2022). While the identical validity issues may or may not arise in other imitative contexts, it is more that the principle and process of establishing validity and reliability, as well as other good measurement practices (Fiedler et al., 2021; Flake & Fried, 2020; Scheel et al., 2021), will almost certainly be applicable in other contexts. Moreover, the SRC imitation task has been used and cited widely (e.g., Brass et al., 2001 has 800+ citations), which means that it is having a substantial impact on various literatures, which is likely to influence the allocation of resources, such as grant funding and hiring decisions. As such, comprehensive validation of such work seems to be important, irrespective of whether the validity concerns raised here generalise to other imitation tasks or not.

We also chose to focus on evaluating the conjoint claim that that the congruency effect in this task indexes imitative tendencies and is resolved by a self-other mechanism that is underpinned by the ToM. However, we would also be curious to see what kind of evidence can be brought to bear on a claim about imitation in general. That is, what is the evidence that the congruency effect in this task, specifically, is related to automatic imitation? We are not talking about outlining assumptions that suggest that observing actions is likely to trigger imitative responses. We are also not talking about evidence that observing actions engages the motor system. They are not sufficient. Instead, we are talking about providing evidence for the validity of using the congruency effect in this task as an index of automatic imitative tendencies. Where is the evidence that shows the incongruent condition requires more automatic imitation than the congruent condition, rather than more attentional control, such as inhibition and selection? And how could researchers use this evidence to validate the inferences they make? For example, in the routine use of this task, how could an individual researcher or research group demonstrate that the congruency effect is actually indexing automatic imitative tendencies, rather than the cost of resolving conflict?

A basic task analysis easily shows that actions are being observed and performed and that there is a cost to response times when these are in conflict. That much we can all agree upon. But, as we outline in some detail elsewhere (Ramsey & Ward, 2020b; Ward & Ramsey, 2024), what we cannot see from the evidence presented to date (e.g., Heyes, 2011; Cracco et al., 2018a), is how this reaction time cost is specifically tied to automatic imitative tendencies, rather than the cost of resolving conflict, just like other conflict tasks that do not involve social stimuli (e.g., stroop, flanker). In our view and assessment of the literature, the suggestion that automatic imitative tendencies drive this congruency effect is one possibility amongst many plausible alternatives. We therefore do not agree that evidence showing that movement execution is facilitated by compatible and impeded by incompatible observed movements can used to validate the claim that imitation "exists" (Cracco et al., 2018a; Heyes, 2011). As such, even if one only considers a less elaborate claim about automatic imitative tendencies, which ignores roles for a self-other distinction mechanism and the ToM network, there is still a gap between the measured congruency effect and the inference being made about information processing systems. We leave this claim about imitation in general for others to consider in future work.

A related point is that our focus has been on laboratory tasks that are amenable to study in controlled environments and with neuroscience equipment. They do use social stimuli, in that they depict human actions, but we are not talking about studies that even remotely approximate real-life social interaction. Consequently, there need not be a direct mapping between research in the lab and research in naturalistic settings or "in-the-wild" (Kingstone et al., 2008). For example, real-life social interactions may depend more upon socially specific forms of control than in lab experiments, although this is an empirical question. As such, evidence that validates the claims being made in field studies would still be required. There is simply a very different starting point, in terms of the richness of the social environment, between laboratory-based reaction time experiments and real-life social interactions. In summary, if very simplified social stimuli are going to be used to make inferences about socially specific forms of cognition, then there is a requisite need evidence for the validity of those claims. And furthermore, such claims may not generalise in a straightforward manner beyond the lab. With this said, the ever-growing development of mobile neuroimaging technologies should may make it easier to test neuroscientific questions in more real-world contexts (Redcay & Schilbach, 2019; Shamay-Tsoory & Mendelsohn, 2019).

We have also chosen to focus on the available evidence for the validity of the claims being made. A related discussion, which we do not have space to cover in this work, would concern the need for greater conceptual clarity in addition to providing evidence of validity (Bringmann et al., 2022; Scheel et al., 2021). With all the many and varied forms and possible component processes of imitation (Chartrand & Lakin, 2013; Heyes, 2011), this seems like a ripe avenue for future research. The overall aim would be to provide a clear and justified link between the type or component of imitation under scrutiny and the type of evidence of validity that would be required to substantiate the specific claims being made.

## Conclusion

In this chapter, we have reviewed evidence regarding the neuroscientific foundations of imitation, specifically the SRC imitation task. We have shown that use of such a task to index processes relating to the control of automatic imitative tendencies, which rely on a self-other distinction mechanism that is uniquely tied to human social interaction and engages the theory-of-mind network, lacks essential evidence for various forms of validity. Instead, given current evidence, the best estimate is that this task engages domain-general forms of control that are underpinned by the multiple-demand network. For claims to be supported regarding socially specific forms of control when using this task, robust evidence for each of the four validities that we have outlined above would be required. Fortunately, with the emergence of the meta-science movement over the past 10 years (Munafo et al., 2017; Nosek et al., 2022), there are more resources than ever before available to help unlock the vast potential that social and cognitive neuroscience approaches can offer to understand the mechanisms of human social behaviour, including automatic imitation.

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