Interacting to remember at multiple timescales

Coordination, collaboration, cooperation and culture in joint remembering

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Everyday joint remembering, from family remembering around the dinner table to team remembering in the operating theatre, relies on the successful interweaving of multiple cognitive, bodily, social and material resources, anchored in specific cultural ecosystems. Such systems for joint remembering in social interactions are composed of processes unfolding over multiple but complementary timescales, which we distinguish for analytic purposes so as better to study their interanimation in practice: (i) faster, lower-level *coordination processes* of behavioral matching and interactional synchrony occurring at timescale t^1; (ii) mid-range *collaborative processes* which re-evoke past experiences in groups, unfolding at timescale t^2; (iii) *cooperative processes* involved in the transmission of memories over longer periods occurring at timescale t^3; and (iv) *cultural processes* and practices operating within distributed socio-cognitive networks over evolutionary and historical timeframes, unfolding at timescale t^4. In this paper we survey studies of how the processes operating across these overlapping and complementary timescales constitute joint remembering in social interactions. We describe coordination, collaboration, cooperation, and culture as complementary aspects of interacting to remember, which we consider as a complex phenomenon unfolding over multiple timescales (t^1, t^2, t^3, t^4).

Keywords: joint remembering; interaction; timescales; coordination; collaboration; cooperation; distributed cognitive networks; culture

1. Introduction

Joint activities, from playing rugby to collaborating with classmates on a mathematical problem, rely on the successful interweaving of multiple cognitive, bodily, social and material resources, each anchored in specific historical, social

Interaction Studies 16:3 (2015), **419–450**. DOI 10.1075/is.16.3.04bie
ISSN 1572–0373 / E-ISSN 1572–0381

and cultural environments. Joint remembering is no exception: it involves people engaged in recalling past experiences, which may themselves have been shared. Sometimes people went through the same events as a group (a couple saw movie X at theatre Y on date Z), sometimes they experienced the same event separately (the partners saw the same movie but at different locations and times). So the information re-evoked during joint remembering can be the result of either shared or individual encodings of the same or a similar original event (Barber, Rajaram, & Aron, 2010; Barnier, Sutton, Harris, & Wilson, 2008; Harris, Barnier, & Sutton, 2013; Pereira-Pasarin & Rajaram, 2011).

Social interactions during joint remembering are complex phenomena unfolding over shorter and longer timescales, from milliseconds, seconds, and minutes to days, months, and years. Processes at shorter timescales are regulated by people's ability to respond to actions and intentions, the turn-taking structure given by the reciprocity of roles (e.g. speaker-addressee, giver-taker), their alternation over time, and the expectation of an immediate response (Levinson, 2006, p. 45–46). But this kind of 'human interaction engine' (Levinson, 2006) is supported by and in a range of cultural ecosystems (Hutchins, 2014) evolving over longer timescales (Cowley, 2014; Lemke, 2000; Pedersen & Steffensen, 2014: Uryu, Steffensen, & Kramsch, 2014).

Such cultural ecosystems of human cognition include the kinds of cultural practices in which particular social interactions occur, as well as their social and material histories and the histories of the participants engaged in them (Hutchins, 2014). When people jointly recall shared events in everyday situations (e.g. when partners talking to their friends remember the last movie they saw together), perhaps in the service of shared goals (e.g. to demonstrate and communicate their shared enthusiasm about the movie), there are complex bodily, linguistic and cognitive processes unfolding in synchrony over a micro-timescale, which we label for convenience timescale t^1. People engaged in joint remembering tend to mimic each other's bodily movements and practices (e.g. eye-gaze, manual gestures, and body positions) in a sequential rather than in simultaneous fashion (Bietti, Kok, & Cienki, 2013; Cienki, Bietti, & Kok, 2014). The temporal dynamics of non-verbal behavioral coordination seems to be determined by the sequential organization of the conversations in which joint remembering takes place. These processes typically occur over milliseconds and seconds.

But remembering together in conversations also relies on processes which begin to expand or extend this micro-timescale, such as the dynamics of verbal interactions reflected in cuing attempts, repetitions and turn-taking (Harris, Keil, Sutton, Barnier, & McIlwain, 2011; Harris et al., 2013; Harris, Barnier, Sutton, & Keil, 2014; Meade, Nokes, & Morrow, 2009). While there are no sharp distinctions between processes operating over seconds to those operating over minutes, we can for analytic convenience identify a mid-range timescale t^2. At this timescale, in contrast to the cognitive processes that govern other collaborative activities (such as collaborative problem-solving or joint reasoning), remembering together involves re-evoking a shared or partially shared past distributed among interacting partners (Barnier et al. 2008; Bietti, 2012, 2014; Harris, Paterson, & Kemp, 2008; Hirst & Echterhoff, 2012; Michaelian & Sutton, 2013; Rajaram & Pereira-Pasarin, 2010; Sutton, Harris, Keil, & Barnier, 2010). Such re-evoking of past experiences involves the human capacity for mental time travel: the “faculty that allows humans to mentally project themselves backwards in time to re-live stages of their lives, or forward, to pre-live events” (Suddendorf & Corballis, 2007, p.299). When measuring the outcomes of re-evoking the past in joint activities, it has been shown that collaboration can inhibit or facilitate individual recall (e.g. Basden, Basden, Bryner, & Thomas, 1997; Hyman, Cardwell & Roy, 2013; Meade et al., 2009; Weldon & Bellinger, 1997). The acts of mentally travelling back in time in social interactions as well as the performance outcomes of these activities are phenomena occurring at a slightly longer timescale t^2. They are influenced by how people coordinate verbal and non-verbal behaviors at a t^1, but do not fully depend on that.

What goes on over t^2 has to be related to something that occurred in the past if we are using the term ‘remembering’ rather than talking about some other kind of cognitive activity. Although of course our individual and shared memories do not always represent past events accurately, they do make claims on and about that past (Sutton, 2008). We relate such ‘pastness’ and outcomes of joint remembering to our second timescale in the model (see Figure 1). At this second timescale, we find processes of collaboration in order to achieve something, rather than coordination, which need not depend on specific intentions, plans or goals. Collaboration involves taking the intentions, plans and goals of others into account (e.g. Gordon & Theiner, 2015; Knoblich, Butterfill, & Sebanz, 2011, Pacherie, 2013). Therefore, collaboration plays a central role in guiding acts of going back in time in our minds in social interactions. During joint remembering collaboration influences the action and planning of interacting partners and shapes interactive outcomes, such as when partner A asks “Do you remember the name of the steakhouse we had lunch at last week?” B replies: “Yes, I do, it′s name was Cambalache”, and A acknowledges B: “Yes you’re right, the place with the nice terrace near the river”. This short remembering sequence (Question => Answer => Acknowledgement) illustrates that joint remembering goes beyond coordinating verbal and non-verbal behaviors over time. It also shows how each interacting partner’s intentions, plans and goals come into play.

So far, there is still something missing if we want to understand how people remember together in the real-world. Joint activities in which people remember together are also anchored in longer-term cooperative and cumulative group dynamics between people with a history of interaction, which we can characterize as typically operating at a timescale t^3 of hours and days. But this timescale stretches, because these processes typically involve a constant interaction between internal cognitive resources (such individual biological memory resources) and external cognitive resources (such as other people and technology) (Donald, 1993; Michaelian & Sutton, 2013; Sterelny, 2012; Sutton et al. 2010). Such interactions lead to an accumulation of knowledge and skills over cultural-historical time, but this has cumulative downstream effects on ontogenetic development because it transforms the social and cultural environments in which subsequent generations of learners grow up (Sterelny, 2012).

The knowledge and skills involved are partly transmitted culturally and historically and learnt throughout complex communication chains, which play a key role in the formation and transmission of collective memories (Wertsch, 2002, 2009) within mnemonic communities (Zerubavel, 2003). Studying the transmission of knowledge and skills that enable the formation of collective memories takes us into consideration of a macro cultural timescale or t^4 (Figure 1).

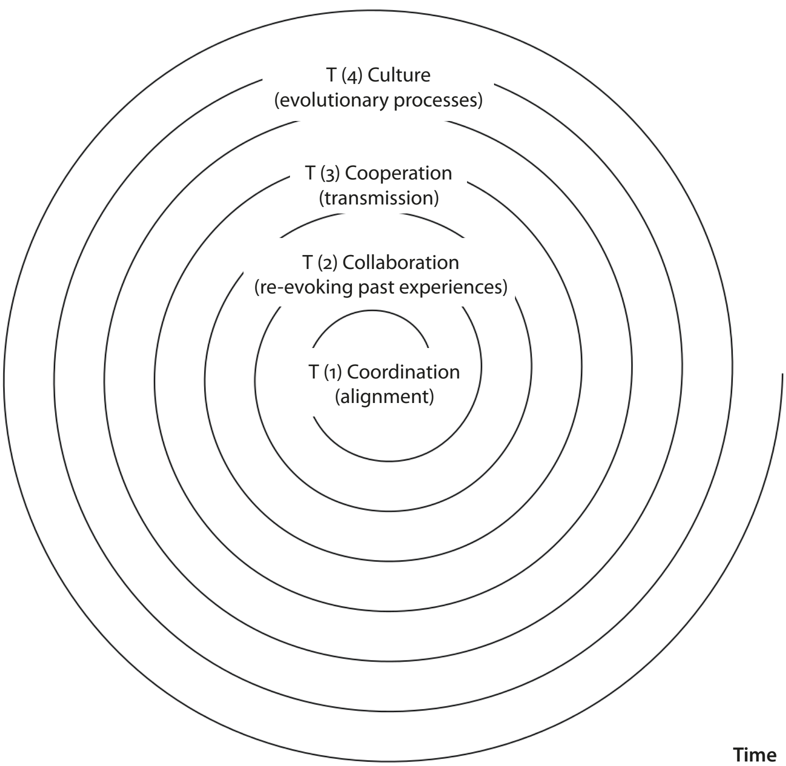

Figure 1. Multiple timescales of joint remembering

As Figure 1 shows, the long-term processes unfolding over t^4 are also affected (and partly constituted) by shorter processes occurring over t^1, t^2, and t^3. That is, the way collective memories emerge and are transmitted over longer, cultural timescales (t^4) partly depends on the human ability to coordinate verbal and non-verbal behaviors over t^1, the human capacity to mentally travel back in time jointly in collaborative social interactions over t^2, and on the diachronic processes of cooperation by which enduring groups form and function over t^3. Purely for analytic convenience, we adopt these four terms to describe processes operating at each timescale. Situated one level beneath longer-term cultural processes, we can treat 'cooperation' as labeling the most inclusive, general, and enduring processes by which groups engage in the diachronic management and negotiation of the shared past. At shorter timescales, 'collaboration' is a useful term for the active and often deliberate sharing of actions and experiences for mutual benefit, while in turn the processes of 'coordination' can include faster and more dynamic interactions of which participants need not be explicitly aware (compare Sterelny 2012; Sutton 2013, p.30).

In this paper we attempt to understand how processes operating across these distinct timescales interact with and complement each other in joint remembering. Firstly, we review literature dealing with aspects of verbal and non-verbal coordination in micro-level social interactions. Secondly, we contrast these studies on the coordination of brains, language and bodies during social interactions with the seemingly contradictory finding that collaboration between interacting partners is rarely beneficial to recall. Thirdly, we suggest that the possible costs of remembering with other people can be linked to the malleability and adaptability of human memory as we coordinate over slightly longer timescales, and hence to the human capacity for engineering hybrid cognitive networks throughout evolutionary and cultural history. Malleable memories as well as cultural–cognitive hybrid networks may have created the conditions for the emergence of large-scale collective memories. Finally, we argue that coordination, collaboration, cooperation, and culture reveal complementary aspects of interacting to remember, which we consider a complex phenomenon unfolding at multiple interanimating timescales. The literatures we seek here to critically integrate are diverse and not always effectively integrated in current research. In order to redress this situation, we provide extensive references throughout, aiming to encourage students of memory across the disciplines actively to forge clearer cross-disciplinary conversations.

2. Timescale #1: Coordination Processes

Conversations about past experiences are one way in which people develop shared memories of the past (Bietti, 2012, 2014; Middleton & Brown, 2005; Hirst & Echterhoff, 2012). The mechanisms involved when individuals are engaged in conversations often include the coordination of linguistic and bodily resources (e.g. gesture, gaze, posture, and facial expressions) in order to achieve shared goals (e.g. to try jointly remember where we left the car parked).

Conversations are joint activities (Clark, 1996; Clark & Brennan, 1991) in which partners have to "share or synchronize aspects of their private mental states and act together in the world" (Brennan, Galati, & Kuhlen, 2010, p. 304). These types of coordination dynamics can occur without conscious awareness (Dale, Fusaroli, Duran, & Richardson, 2013; Rączaszek-Leonardi & Cowley, 2012). Coordination dynamics between interactants can be reflected in cases of behavioral alignment. We use the general term 'alignment' (Tollefsen & Dale, 2012; Wachsmuth, de Ruiter, & Kopp, 2013) to refer to the holistic phenomena by way of which "individuals, over time, change their affect, behavior, and cognition as a direct result of their interaction with one another" (Paxton & Dale, 2013, p. 1121). That is, we use 'alignment' as an umbrella concept to refer to cases of behavioral matching as well as interactional synchrony. To relate this distinction to our model (see Figure 1), we associate instances of behavioral matching with forms of co-action driven, to an important extent, by perception-action links (e.g. Chartrand & Bargh, 1999) and by priming effects based on semantic relationships occurring at a local level (simultaneously or almost simultaneously).

We consider instances of interactional synchrony as the "degree of behavioral congruence between the behavioral cycles of two or more people" (Bernieri & Rosenthal, 1991, p. 241). This goes beyond the mere fact of mirroring each of the interacting partner's behaviors, and includes cases of behavioral complementarity that may lead to synergistic couplings over longer stretches of time. We explain each of these concepts, describe different types of coordination dynamics for social interaction (2.1 and 2.2), and review empirical studies showing how bodily resources may affect remembering in interactive contexts (2.3), Finally, we report the implications for joint remembering (2.4 and 2.5).

2.1 Behavioral matching

Cases of human behavioral matching arise when two or more people perform the same behavior at (roughly) the same time. Behavioral matching involves the mirroring of co-speech gestures (e.g. Goldin-Meadow & Alibali, 2013; Holler & Wilkin, 2011), facial expressions (e.g. Sato & Yoshikawa, 2007), postures and body movements (e.g. Chartrand & Bargh, 1999), and linguistic structures (e.g. Ireland et. al, 2011). Behavioral matching in dialogue is manifested in the repetition of lexical items or syntactic constructions across interlocutors' utterances (Allen, Haywood, Rajendram, & Branigan, 2011), or in copying features of others' spoken signals such as intensity, pitch, and voice quality (Levitan & Hirschberg, 2011). It smooths communication by enhancing accessibility of lexical and syntactic resources. Thus, behavioral matching in dialogue or 'interactive alignment' as some authors prefer to call it (Pickering & Garrod, 2004) is argued to reinforce the 'implicit common ground' between speakers, and allow for anticipation of upcoming utterances (Pickering & Garrod, 2013).

Research on behavioral matching shows that interactants' mimicking each other's behavior can foster prosocial behavior, creativity and mood regulation (Chartrand & Lakin, 2013). In contrast, other studies suggest that less mirroring among interacting partners tends to occur when their goal is to disaffiliate (Stel, van Baaren, & Vonk, 2008). Hence, human behavioral matching of multiple bodily and linguistic resources at a micro-timescale of milliseconds appears to be a basic cognitive tuning process that facilitates social interactions.

2.2 Interactional synchrony

Research on interactional synchrony has shown that interactants' bodily resources can also be coordinated in time in a sequential fashion, thus creating the conditions for the emergence of behavioral patterns (e.g. Bernieri & Rosenthal, 1991; Condon & Ogston, 1966; Schmidt, Morr, Fitzpatrick, & Richardson, 2012). Interactional synchrony has been shown to be a social and motor factor increasing rapport (e.g. Bernieri, Davis, Rosenthal, & Knee, 1994), and to play a crucial role in caretaker- infant interaction (e.g. Nomikou, Rohlfing, & Szufnarowska, 2013; Mühlhoff, 2014; Trevarthen, 2005).

Shockley and colleagues have demonstrated a direct link between the stress patterns of the words spoken by members of dyads and the way they synchronize their postural sway during conversational interactions (Shockley, Baker, Richardson, & Fowler, 2007). A study on gaze by Richardson and colleagues additionally reported tight coupling of eye gaze during conversational interaction (Richardson, Dale, & Kirkham, 2007). As their subjects discussed a work of art, their eye movements became distinctly synchronized in time. Similar processes are likely to be in operation, though harder to study, in fast-paced dynamic group activities such as team sports (Williamson & Sutton, 2014).

Research on interactional synchrony has focused not only on how one or two behavioral channels are coordinated in sequential manner, but also on how several of these channels complement each other during social interaction as a self-organizing property of human interaction (Dale et al., 2013; Fusaroli & Tylén, 2012; Fusaroli et al., 2012). Louwerse and colleagues found that in a route-communication task, participants synchronized within multiple behaviors (i.e. facial expressions, manual gesture, touching face and speech) (Louwerse, Dale, Bard & Jeuniaux, 2012). This example of multimodal synchrony led the authors to suggest that behavioral resources in interaction constitute a holistic web of mutual dependencies. Dale and colleagues claim that interpersonal synchrony is one way of reducing the cognitive load of interlocutors, thereby condensing the complexity of the interaction (Dale et al., 2013).

2.3 Bodily resources and remembering in interactive contexts

So far little attention has been paid to the role played by bodily resources during joint remembering in social interactions in controlled experimental settings. This means studying whether differences in the use of bodily resources in both listeners and speakers may influence recall performance during social interaction. However, when considering the compelling evidence collected in experimental settings when looking at the influence of manual gesture on higher cognitive functions in individual tasks (spatial navigation, memory, learning, etc.), the landscape for the design of controlled experimental studies aimed at shedding light on these topics in interactive contexts seems promising. For example, a series of studies on gesturing while speaking have demonstrated that manual gesture improves learning (e.g. Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Sauter et al. 2012) and performance in simultaneous memorization tasks (e.g. Stevanoni & Salmon, 2005). Regarding gaze, several studies (e.g. Mason, Hood, & Macrae, 2004) have suggested that a person's direct gaze (in contrast to averted gaze) towards a target enhances its subsequent memorability – of the object gazed at – and significantly improved the gazer's recognition of it. Research on body posture has found compelling evidence regarding the important role that bodily states play in encoding and retrieval personal memories (e.g. Dijkstra & Zwaan, 2014). Studying the interactive functions of head-movements like nodding during storytelling, a human activity which joint remembering uses to a great extent, has shown the ways in which head-movements act as embodied resources for back-channeling, that is as a mode to signal the degree of the listener's attention to the story being narrated (Bangerter & Clark 2003).

2.4 Alignment and joint remembering

Research on specific aspects of behavioral matching in dialogue (Pickering & Garrod, 2004) suggests that priming effects play a central role in successful communication. In this context, successful communication refers to "the development of similar representations in the interlocutors" (Pickering & Garrod, 2006, p. 203). Although it is a long way from the development of similar representations in interacting partners to the actual collaborative activity of joint remembering in social interactions, research on collaborative recall has reported that mnemonic benefits were associated with interactive cueing, and repetition in conversations about shared past experiences (Harris et al. 2011; Harris et al. 2014, Meade et. al, 2009). Interactive cuing and repetitions are conversational phenomena that rely on priming effects to a large extent.

Only recently has research on alignment focused on joint remembering (Tollefsen, Dale & Paxton, 2013). In a recent observational study on multimodal alignment during the collaborative remembering of shared, autobiographical events (such as vacations) in small intimate groups (close friends and family members) at their homes, Cienki and colleagues (Cienki et al., 2014) annotated video recordings by assigning binary values to a range of behavioral channels (n=19) for every 500- millisecond interval, designating whether each of these behaviors was performed or not at that time by each of the participants. These behaviors were clustered into three categories: (i) gestural behaviors; (ii) postural behaviors and (iii) gaze behaviors. For each behavioral variable, they computed two types of alignment rates. Time points where two or more participants concurrently performed a given behavior were counted as instances of simultaneous alignment; time points where a behavior was initiated within ten seconds after another participant had withdrawn that same behavior were counted as sequential alignment. For all coded behaviors, they counted instances of simultaneous and sequential alignment defined as such, and compared observations to a chance baseline. The results showed that sequential alignment rates were significantly higher than chance for all three behavioral categories.

Based on these results, Bietti et al. conducted a more fine-grained analysis focusing on the delay of sequential alignment (Bietti et al., 2013). They computed the distribution of all time lags between the withdrawal of a behavior by one participant and the instantiation of that same behavior by another participant. A notable trend was that, for all of these clusters of behaviors, the highest counts of behavioral alignment corresponded to a delay of a single second. This showed that sequential alignment occurred very fast, suggesting that participants tended to mimic each other behaviors immediately after observing them. However, whereas the sequential alignment rate declined as a function of lag length, that is, as time progressed during the unfolding social interaction, Bietti et al. found that sequential alignment rates only reached chance level for lags of around 20 seconds. These findings led the authors to make two suggestions. Firstly, instances of behavioral copying, coincidental rather than specifically related to and relevant to joint remembering, may have provoked that the highest point of behavioral resonance across participants corresponded to delay of a single second. Secondly, speech production processes during joint remembering may have caused that participants tended to mimic each other's behaviors up to 20 seconds after they were first observed (Bietti et al. 2013; Cienki et al. 2014). In speech production processes, it has been found that interactive linguistic alignment plays an important role in the creation of common ground between speakers during joint remembering (Bietti & Galiana-Castelló, 2013).

2.5 Linking micro and mid-range timescales

A recent study (Bietti & Baker, submitted) examined the joint remembering of a previous interactive encounter in which groups had to collaboratively design its dream house under certain constraints relating to number of occupants, relationships, and funds. The results suggested that the most elaborated items during co-design were the best-remembered ones during joint remembering, measured by the amount of information remembered rather than memory accuracy. The analysis also showed that some of the categories less elaborated in co-design were omitted during joint remembering. Additionally, Bietti and Baker reported that participants collaboratively remembered better those moments of creativity when they were more jointly involved in elaborating the features of their design. That is, they remember better what initially generated most joint activity during the previous co-design phase. Based on these results, Bietti and Baker concluded that participants did not necessarily collaboratively remember what was more important, but rather what initially generated most joint activity during co-design.

Other studies measuring the outcomes of joint remembering that consider the quality of verbal interactions among interacting partners have found that repetitions and cross-cuing (the co-construction of utterances among speakers) tended to facilitate group recall (Harris et al. 2011; Meade et al. 2009). As the focus of these studies (Harris et al. 2011; Meade at al. 2009) was the outcome of joint remembering processes occurring over a t2, we review them further in the next section.

3. Time scale #2: Collaborative processes

Remembering with other people goes beyond the coordination of verbal and non-verbal resources in synchronized fashion over time. At some point during the joint activity, interactants have to collaboratively create a shared account or expression of the past in order to actually remember together, as distinct from doing something else (e.g. imagining together). This means that joint remembering is not only about how this specific kind of social interaction is coordinated and unfolds over time, but also the collaborative processes that for example enable interactants to cue each other's memories (e.g. Harris et al. 2011; Meade et al. 2009), and whether or not familiarity (Harris, Barnier & Sutton, 2012; Harris et al. 2014; Rajaram & Pereira-Pasarin, 2010;) or shared encoding (Harris et al. 2013) influence recall.

This section is organized as follows: first, we discuss research on the benefits and costs of collaboration in different cognitive tasks (e.g. Bahrami et al., 2010) and introduce the concept of transactive memory (Wegner, 1986) (3.1); then we critically evaluate the collaborative recall paradigm in cognitive psychology (Rajaram, 2011; Weldon & Bellinger, 1997), developed to study the costs and benefits of collaboration in recall (3.2).

3.1 Benefits and cost of collaboration

When paying particular attention to the outcomes of collaboration occurring at a timescale from seconds to minutes (t^2), evidence suggests that in many cases two or more interacting partners do perform better than any one person alone but not better than the same number of people working separately and pooling their results (Basden et al. 1997; Rajaram & Pereira-Pasarin, 2010; Weldon & Bellinger, 1997). However, several studies have indicated that collaboration can be beneficial under specific circumstances (e.g. Bahrami et al. 2010; Fusaroli et al., 2012). In a two-choice perceptual task, Bahrami and colleagues (2010) demonstrated that collective decision-making in dyads can significantly be improved if individuals have similar individual effectiveness in visual discrimination and they can communicate their own relative confidence about the perception task. However, when free information sharing and communication were restricted, the group benefit disappeared.

Research in organizational psychology, collaborative learning, cognitive psychology and philosophy of mind suggests that under specific circumstances teams of experts, groups of learners and long-term couples can form transactive memory systems (Hollingshead 1998; Jackson & Moreland 2009; Lewis, Lange, & Gillis, 2005; Ren & Argote 2011; Sparrow, Liu, & Wegner, 2011; Theiner, 2013; Wegner, 1986). A transactive memory system is group memory that "involves the operation of the memory systems of the individuals and the processes of communication that occur within the group" (Wegner, 1986, p. 191). In order for a transactive memory system to develop, once information is distributed in a certain way among the members of the group, the individuals within the system must share the higher-level knowledge that there are domains of expertise within the group, distributed in a certain way. When meeting these two requirements, individuals within a transactive memory system can distribute cognitive labor, such that each member only has to assume responsibility for learning information within his or her own domain of expertise, while knowing (explicitly or implicitly) that each other member of the transactive memory system is accountable for their area of expertise. Thus, within a transactive memory system, individuals do not waste cognitive resources trying to remember something their partner is an expert in. Hence, groups that are able to develop transactive memory systems may have a greater chance of performing better than groups in which such a distribution of cognitive labor does not occur and their members remember information individually (Wegner, Erber, & Raymond, 1991).

3.2 The collaborative recall paradigm

Research on transactive memory, in organizational psychology for example, has tended to be satisfied with the criterion under which a group will inevitably outperform an individual. Therefore, if a group performs better than an individual in memory tasks, it may be the case that this better performance was due to the ability of the group to develop a transactive memory system. But in cognitive psychology, studies of shared remembering have imposed a higher bar or criterion for success: that the group's performance should be better not just than that of any one individual, but than that of the same number of individuals working separately as a 'nominal' group. Numerous experimental studies in the 'collaborative recall' paradigm have found that remembering in a group often, counter-intuitively, impairs the group's overall memory performance compared to the pooled, non-overlapping recall of the same number of individuals remembering alone (Basden et al. 1997; Rajaram & Pereira- Pasarin, 2010; Weldon & Bellinger, 1997).

In general, such experiments consist of a learning or encoding phase in which participants are presented lists of words and are asked to remember them (baseline). Next, participants are instructed to recall these words either individually or in a group (first recall). And finally, all participants are asked to recall the same stimuli again individually (second recall) (Barnier et al., 2008). Studies in this tradition have consistently found that joint remembering does inhibit individual recall performance rather than promoting it (Andersson & Rönnberg, 1995; Blumen & Rajaram, 2008; Congleton & Rajaram, 2011; Henkel & Rajaram, 2011). The 'retrieval disruption hypothesis' (Basden, Basden, & Henry, 2001) has been the typical way of explaining the collaborative inhibition effect: seeing or hearing other people's responses disrupts the way each individual organizes his/her retrieval sequences and strategies, thus causing the collective failure to achieve potential (Barber et al. 2010; Barber & Rajaram, 2011; Basden et al. 1997; Rajaram, 2011).

However, within the collaborative recall paradigm, recent studies (Harris et al. 2011; Harris et al. 2014; Meade et al. 2009) suggest that in some groups and under specific circumstances, remembering with other people can be less detrimental, or even beneficial. For example, in a study that compared collaborative recall performance in groups of non-expert and expert pilots (Meade et al. 2009), collaborative facilitation was found in groups of expert pilots. This is to say that the performance of the groups of expert pilots was better than the sum of the performances of each of their members working separately. This positive effect was not found in the non-expert groups where collaborative inhibition was observed. Meade and colleagues analyzed the verbal interactions in both types of groups, and discovered that one key factor in successful collaboration for the expert group was the repetition of one's partner's contributions in order to make explicit common ground and support further elaboration. This communicative strategy was absent in the groups of non-experts that showed collaborative inhibition. The authors indicated that the effective communication found in the groups of expert pilots came from training and expertise in which the exchange of information is crucial.

In another series of studies focusing on the benefits and costs of collaboration in older couples, Harris et al. (2011) have shown that under some conditions when long-term married couples re-evoke shared experiences together they can remember information that both individuals in isolation appear to have forgotten. However, the conditions and the kind of material that the couples are asked to remember play a central role in the collaborative facilitation effects. Despite considerable differences in recall performance across couples, Harris et al. (2011) eliminated collaborative inhibition when older couples recalled lists of both non-personal and personally relevant material. Factors leading to such mnemonic benefits included shared retrieval strategies, interactive cueing styles, and repetition (Harris et al. 2011; Harris et al. 2014). In other words, verbal interaction style and communication play a central role in improving collaborative performance (Harris et al., 2011; Harris et al., 2014). These findings were in line with the results shown in the study on groups of experts and non-expert pilots (Meade et al., 2009).

Besides the central role that these kinds of verbal communication play in the emergence of collaborative facilitation effects, Harris et al. (2013) examined whether the conditions (individual vs. shared) in which people (strangers vs. friends) encoded the information to be recalled later influence recall performance. The study reported that sharing the encoding of information had later mnemonic benefits. That is, the elimination of collaborative inhibition in the collaborative recall stage was correlated with having previously shared the encoding of the information. When collaborating groups were instructed to discuss and generate the items which they would later have to recall, these groups performed as well as nominal groups (Harris et al. 2013).

These positive results linked to the elimination of collaborative inhibition due to shared encoding were found in both groups of strangers and friends. This indicates not only that verbal communication style plays a key role in creating the right conditions for more effective collaboration, but also the significance of whether interactants in a joint remembering task went through the experiences being recalled as a group – thus sharing the encoding process – or on their own.

Thus processes operating at the timescale of second and minutes (t^2) are dependent on group processes operating over days or longer (t^3).

4. Time-scale #3: Cooperative Processes

Interacting to remember over timescales of hours, days, weeks, and months (t^3) is grounded both in residual traces of social interactions occurring over t^1 (e.g. coordination of verbal and non-verbal resources) and in their outcomes at t^2 (e.g. collaboration while re-evoking past experiences). The transmission, learnability, persistence, and transformation of memories in and across social groups over time constitute the temporal dynamics of t^3. In this section we discuss how memories are transmitted across multiple individuals along communication chains (4.1); and the ways that malleable memories may create the conditions for the social contagion of memories. (4.2). In the next section (5), we focus on the cultural processes enabling the formation of long-term collective memories.

4.1 Transmission of memories

Bartlett's (1932) seminal research on how individual recollections change over repeated retelling provides a general framework for understanding the reproduction and transmission of memories over time. He used two primary techniques to investigate such phenomena: repeated reproduction and serial reproduction. In repeated reproduction participants learn new material (e.g. stories) and then recall it over multiple occasions over time, without being exposed to the same original stimulus. In serial reproduction, in contrast, a participant (A1) is asked to learn new material (e.g. images and stories) and then write or draw (depending on the material) from memory the new material just learnt. Next, A1 leaves the testing room, and a new participant (A2) sees the previous image or reads the previous story generated by A1, and is asked to write or draw from memory the new material just learnt.

In the original experiments ten participants made up the transmission chains (Bartlett, 1932). By comparing recall performance in both conditions, results suggested that in repeated reproduction (same participant), compared to serial reproduction (multiple participants), more information was preserved over time (Bartlett, 1932; Bergman & Roediger, 1999; Carbon & Albrecht, 2012; Roediger, Meade, & Bergman, 2001; Roediger, Meade, Gallo & Olson, 2014). Multiple re-telling of the same story by a single participant seemed to consolidate and enhance future recall compared to what happens in serial reproduction (Roediger et al., 2014).

Memory research has focused more on experimentally testing recall performance using repeated reproduction rather than serial reproduction techniques (Bergman & Roediger, 1999; Gauld & Stephenson, 1967; Wagoner & Gillespie, 2013; Wheeler & Roediger, 1992). A possible reason for this is that the serial reproduction of memories passed along chains of participants has shown how the final reconstruction could be very different from the target message presented at the beginning of the chain. Hence, it would be difficult to measure and track down these changes over transmission chains. However, when we are interested in the transmission and learnability of memories in and across social groups and communities over time, we need to pay particular attention not to how the same individual retells the same story multiple times but how these stories spread across multiple individuals and social groups. Thus, the serial reproduction condition is potentially more relevant when focusing on larger and more complex social dynamics.

Bartlett's 'transmission chain' method, using images and stories as original stimuli, has inspired many studies on how verbal descriptions based on individual memories change over time (Mesoudi, 2008; Mesoudi & Whiten, 2008; Ost & Costall, 2002; Roediger et al., 2014; Xu & Griffiths, 2010). Experiments dealing with the transmission of verbal descriptions typically use scripts of typical event sequences such as 'going to the restaurant' as stimuli. They find that over time the descriptions made by participants change significantly as the transmission chains become more distant from the event in which the original stimuli was presented (e.g. Mesoudi & Whitten, 2004). Such changes in verbal descriptions ranged from generalizations and abstractions of stories (Mesoudi & Whiten, 2004), distortions based on memory biases (Xu & Griffiths, 2010) to strengthening of cultural stereotypes (Bangerter, 2000; Kashima, 2000; see Mesoudi & Whiten, 2008 for review). Nonetheless, in a recent study that examined the influence of social interaction in transmission chains, Tan and Fay found that in cases in which transmission chains involved adjacent participants freely interacting with one another (interactive chains condition) more accurate information was preserved (e.g. fewer abstractions and generalizations were found) compared to what they found in one-way transmission chains (non-interactive chains condition) (Tan & Fay, 2011). In one-way transmission chains, participants had to listen to audio-recordings of narrations produced by a previous generation of participants, and then recorded their own accounts of what they had listened to, which were passed on to a new generation of participants for the same procedure (Tan & Fay, 2011). Tan and Fay (2011) reported that listeners' feedback (such as requests for further information and backchannel responses) played an important role by improving the narrators' information recall accuracy.

4.2 Social contagion and malleable memories

Research on the malleability of human memory (Loftus, 1979, 2005) has shown how we can incorporate misinformation under certain social and cognitive conditions. This line of inquiry has led cognitive and forensic psychologists to focus on memory errors and misinformation effects caused by social contagion (Numbers, Meade, & Perga, 2014; Meade & Roediger, 2002; Muller & Hirst, 2014; Roediger et al. 2001). Several studies on social contagion using confederates have reported that participants remembered more incorrect elements inserted by the confederate than non-inserted incorrect elements, that is, new incorrect items that the participants inserted on their own (e.g. Roediger et al., 2001). In addition, other studies reported that confederates' false memories are highly contagious to other subjects after social interaction (Echterhoff, Groll, & Hirst, 2007; Hirst & Echterhoff, 2012; Roediger & McDermott, 2011). Based on the same social contagion effect, recent studies have focused on its potentially adaptive features, as a trust-based mode for promoting cultural learning and cooperation among in-group members (Wheeler, Allan, Tsivilis, Martin, & Gabbert, 2013) and enabling the formation and maintenance of mnemonic communities which are the basis for the emergence, formation and transmission of collective memories (Fagin, Yamashiro, & Hirst, 2013).

5. Time scale #4: Cultural processes

The formation of collective memories occurs at a community level and goes beyond the transmission of memories in communication chains or the possible effects of social contagion. Collective memories are supported by distributed cognitive networks. Distributed cognitive networks (Donald, 2007) integrate embodied human minds into larger institutional structures with their own histories and dynamics. In distributed cognitive networks technology, too, plays a central role. A well-known example of an operating distributed cognitive network guiding the formation of socially distributed memories can be found in the multi-layered processes involved in the teaching of the history of children's own nation in schools. When pupils start learning about their country's past in institutional settings, they rely on information coming from multiple resources such as teachers, textbooks, and institutional rituals (e.g. commemoration of important historical dates). In addition, pupils are also exposed to their parents' and family's memories and opinions about their national history, as well as information and evaluations they may come across in films, on television, and through social media platforms. As young children develop (in ontogenetic time), institutionalized national histories may be subjected to revision, and as result, teachers' opinions and accounts presented in textbooks may also change. Their friends, own readings and personal interests may affect their knowledge about the country's past. Technologies used to transmit such national histories may also change too, as we witness in the development of social media, virtual reality and tangible interactive technology. As the example suggests, although distributed cognitive networks do operate in a synchronic dimension (e.g. the pupil performing a national hero on stage during the commemoration of Independence Day at the school), their distinctive feature comes from linking embodied human minds to institutional structures. These are two sides of the same coin, co-evolving over time.

This section is about the timescale t^4, at which such large-scale and long-term cultural and evolutionary processes occur. First we discuss research that has dealt with the formation of collective memories from a socio-psychological perspective (5.1). Then, we relate the formation of such higher-level cultural and cognitive products (e.g. collective memories) to the creation of distributed cognitive networks that enabled people to learn, remember, transmit and accumulate knowledge over ontogenetic time (5.2).

5.1 The formation of collective memories

While bracketing for current purposes the philosophical debate about whether groups can have a mind, and therefore can themselves form collective memories (Sutton, 2008; Theiner, 2013; Tollefsen et al. 2013; Wilson, 2005), we may consider that collective memories can be operationalized as "individual memories shared across a community that bear on the community's identity" (Coman, Brown, Koppel, & Hirst, 2009). These collective memories may belong to an identity project that members of groups often use to preserve an established group history and maintain group cohesion (Wertsch, 2002).

A number of studies have begun to investigate how different social, cognitive, and linguistic phenomena influence collective memory-making, such as conversational roles (Hirst & Manier, 1996), expertise (Hirst & Manier, 2008), and conversational silence (Stone, Coman, Brown, Koppel, & Hirst, 2012). Hence, the ways in which members of a community share memories are crucial in understanding how individual memories are shaped and how collective memories are formed through communication (Coman et al., 2009; Hirst & Manier, 2008; Hirst & Echterhoff, 2012).

Several studies on the influence of changing social roles in conversations about past experiences have reported that interacting partners tend to adopt complementary roles while jointly constructing shared accounts of the past (Hirst & Manier, 1996; Hirst et al., 1997). These studies have identified three complementary social roles: narrators, mentors and monitors. Partners who assume a narrator role take the lead in the conversation about past experiences and tend to also talk about experiences that were not shared by other members of the group. Secondly, those who take a mentor role support narrators by providing them with memory prompts to elaborate further. Thirdly, partners who assume a monitor role are in charge of assessing whether the narratives being told are accurate and whether it is the case that specific elements are missing (Hirst & Manier, 1996). These three main conversational roles during joint remembering in social interactions are flexible to some extent and depend on the interacting partners' identities, goals and actions in relation to the task. This means that in family conversations about first-hand experiences of national political events (e.g. "what I was doing when the war began") around the dinner table elder partners switch roles as narrator, mentors and monitors for generational reasons (they have lived longer than their children), whereas their children typically take the role of mentors and monitors (based on family memories learnt previously) but rarely as narrators (Bietti, 2010).

Other studies that have taken this line of research into more controlled experimental conditions (e.g. Cuc, Ozuru, Manier, & Hirst, 2006) show that in groups in which interacting partners assume the role of dominant narrators, there are higher chances of the group forming a collective memory. Brown, Coman and Hirst (2009) studied whether there were important distinctions between being a dominant narrator and an expert for the formation of a collective memory in conversations in small groups. They reported that both aspects can be independent of each other (being an expert does not necessarily lead to being a dominant narrator), but both facilitated the formation of a collective memory. In addition, Brown et al. argued that compared to those partners with the perceived status of experts, dominant narrators had more chances of implanting false memories on other group members (see Coman et al., 2009 for a review).

In relation to ways in which what remains unsaid in a conversation shapes the forging of a collective memory, Stone et al. have demonstrated that remaining selectively silent about a topic not only induces these aspects to be less accessible (i.e. forgetting), but also provides a functional mechanism for forging a collective memory (Stone et al., 2012; Stone & Hirst, 2014). Based on the notion of public silence, defined as a silence experienced by a mnemonic community, ranging from small groups to nations or religious groups (Stone & Hirst, 2014, p. 314), Stone and Hirst argued that not all silences have the same influence on the formation of a collective memory: "If the public silence is related to what is mentioned, the resultant individual and collective forgetting would be greater than if the public silence was unrelated to what is mentioned " (Stone & Hirst, 2014, p. 322).

The evidence presented in these studies illustrates the important role that social factors occurring at macro timescale t^4 (e.g. social identity, status, dominance and power relations) have in the formation of collective memories over shorter timescales.

In a recent study focused on the role of collaboration in the formation of collective memories, Barber and colleagues reported that even when collaboration is a detriment to group recall, it can foster the creation of collective memories (Barber, Rajaram, & Fox, 2012). In relation to these findings, some studies have employed agent-based modeling (ABM) to investigate the transmission and spread of collective memories among larger social groups (Coman, Kolling, Lewis, & Hirst, 2012; Luhman & Rajaram, 2013). In a study that used ABM to investigate collaborative inhibition in larger social groups (Luhmann & Rajaram, 2013), the results obtained through computer simulations were in accord with some effects observed in experimental studies, namely that as group size increases, so does collaborative inhibition. Furthermore, the computer simulations also indicated that information (e.g. memories) diffuses across social networks (Luhmann & Rajaram, 2013). These results are in line with the findings coming from research on the transmission of memories over communication chains (e.g. Tan & Fay, 2011) and the evolutionary and cultural advantages of social contagion (e.g. Wheeler, 2013). All this evidence suggests that questions about collectivity seem to be quite independent of questions about whether outcomes of social interacting to remember are beneficial for preserving memory accuracy.

Wertsch (2009) maintains that collective memories are composed of representations of the past distributed among people and cultural tools. The interaction between these elements within specific cultural, historical and technological environments creates the conditions for the emergence of collective memories. That is, the formation and transmission of collective memories is constrained by biological, socio-cultural and technological resources as well as by cultural practices. The social, cultural and technological resources depend on cultural differentiations. One culture may supply mnemotechnic practices that distinguish it from others (Wang, 2013). This takes us to the ways in which distributed cognitive networks and cultural ecosystems have constituted enriched environments for joint remembering throughout evolutionary history.

5.2 Distributed cognitive networks

Throughout human evolution, "the social environment, not just individual minds, has become increasingly organized to support the flow of information across the generations" (Sterelny, 2012, p. 27). Several authors assert that human intelligent behavior has its roots in interactions between people, with their adaptable bodies and plastic brains, and social and material environments, and not only in abstract models or representations of human behavior, or in brain tissue (Donald, 1991, 1993; Malafouris, 2013; Sterelny, 2012). Recurrent patterns of human-environmental couplings enable humans to create distributed cognitive networks in culture (Donald, 2007). This is what Donald calls the 'exographic revolution' in human cultural and cognitive evolution (Donald, 1991), and this takes us to a consideration of the longer timescales which form the cultural and evolutionary background to processes of joint remembering (t^4).

The creation of distributed cognitive networks in our species' history enabled people to learn, remember, transmit and accumulate knowledge, supporting the formation of collective memories at the community level. The 'exographic revolution' was driven by novel interfaces between systems of engrams and exograms, defined as memory records or fragments inside and outside the brain, respectively. Engram systems include: motor plans (procedural and skill-related); conditioned emotional response (CER) (automatic response to a stimuli or cue that has been learned from past experiences); perception (familiarity in the form of repeated exposure to a stimulus and perceptual priming); and semantic (factual and abstract) as well as episodic (vivid, concrete and detailed) memories. Exogram systems include the built environment; crafted mnemonic devices; painted and sculpted images; measuring instruments; written records (such as books); mathematical notations; libraries and archives; and electronic media.

Such novel interfaces allowed the significant enhancing of the storage capacity of biological memory systems throughout human cultural evolution. Donald argues that exograms enable human beings to manipulate complex representations by significantly increasing working memory capacity. In this way, non-biological memory storage (such as, now, electronic media) together with bio-memory systems create the conditions for the emergence of distributed hybrid networks formed by interwoven neural capacities and external memory devices.

Donald maintains that due to brain plasticity, the interanimation of exograms and engrams leads to a continuous re-formatting of distributed hybrid memory networks that triggers the updating and re-wiring of the neural apparatus. An example of such adaptations can be observed in new research on the Internet and its effects on memory, which suggests that people's memory is adapting to new computing and communication technology (Sparrow et al. 2011). These new adaptations are reflected in the claim that we "remember less by knowing information than by knowing where the information can be found" (Sparrow et al. 2011, p .778).

This example of bio-memory adaptations due to changes in the material culture is related to the notion of 'metaplasticity' proposed by Malafouris in the field of neuroarchaeology (Malafouris, 2013). Malafouris acknowledges the central role of material culture in the evolution and development of human cognition. He goes further by proposing that the brain can be conceived as both a biological entity and a cultural artifact because of its continuous re-shaping, re-wiring and re-modeling.

Drawing from the use of the term 'metaplasticity' in neuroscience, which is defined as "change in the physiological or biochemical state of neurons or synapses that alters their ability to generate synaptic plasticity" (Abraham, 2008, p. 387), Malafouris (2010) expanded the scope of the term 'metaplasticity' to refer to the properties that emerge as result of the "enactive constitutive intertwining between neural and cultural plasticity" (p. 56).

Although the examples explored by Donald and Malafouris and the study on the Internet's effects on memory were cases of human-tool interaction, distinct from the core kinds of human-human, face-to-face interactions in scaffolding joint remembering that we have been discussing in this paper, they do clearly show how such adaptations are currently taking place. In a co-evolutionary process, people's adaptable bodies and plastic brains may have gradually adapted to such new distributed hybrid memory networks throughout evolutionary history, and vice versa. That is, such networks, as products of human coordinated action over macro-timescales, should have adapted to people's cognitive abilities and biological predispositions.

It may be that when we look at the larger picture, and take into account the web of mutual dependencies in our distributed cognitive networks, the 'costs' of remembering with other people in synchronic (collaboration) and diachronic (transmission) terms may be the price that we have to pay for our high capacity for building and adapting to cultural ecosystems (Hutchins, 2014).

6. Relations between timescales

At the micro-timescales of milliseconds and seconds t^1, when two people are involved in synchronous social interaction, there is a high possibility that verbal and non-verbal behaviors will become temporally aligned and synchronized at an inter-individual level. This also occurs when conversations are about shared past experiences among group members during unstructured social interactions in naturalistic settings. Lags of multimodal alignment between interacting partners during conversations about the shared past reflect the key role that the sequential organization of joint remembering plays in determining the dynamics of events (e.g. changes in gaze direction) occurring over a micro-timescale.

Joint remembering involves not only the coordination of verbal and non-verbal behaviors unfolding at a micro-timescale, but also collaboration to re-evoke past experiences. Interestingly, even though people are excellent coordinators of verbal and non-verbal resources during social interaction over t^1, research on the benefits and costs of collaborative recall indicates that remembering with other people may disrupt rather than benefit memory over t^2 (collaborative inhibition). However, this is not always the case. For specific groups (such as experts and older couples) and under certain conditions (depending for example on the type of material to be recalled), collaboration during joint remembering may bring benefits rather than only costs. Importantly, the characteristics of verbal interactions in which interacting partners engage (such as interactive cueing and repetitions) played a key role when collaborative facilitation effects were observed. These findings illustrate that to some extent and under certain circumstances, what goes on at t^1 may influence what occurs at t^2, and vice-versa.

If we consider how memories are transmitted and evolve across communication chains over more macro-timescales (t^3), more accurate information may be lost as the communication chains gradually move away from the original events. However, although the loss of information may be a natural effect of transmission over time, studies indicate that in interactive chain conditions with verbal interaction more information is preserved compared to what occurs in non-interactive chains with one-way transmission. Here again, the ways in which collective memories are created over a t^3 can be influenced by events occurring over a t^1 (back-channel responses, i.e. "ok," "yeah," and "mmm") as well as over a t^2 (request for further information).

Controlled experimental tasks have provided fundamental insights into the interactional and cognitive mechanisms of joint remembering, as well as its outcomes over multiple timescales, mostly within the confines of the laboratory (except from Harris et al., 2011). Nonetheless, cases of joint remembering in the world outside the laboratory, and the processes driving the formation of collective memories are also driven by long-term interactions, specific cultural dynamics and evolutionary processes, supported by distributed cognitive networks (from the creation of written records to electronic media) and social factors (e.g. asymmetric power relations, social roles and identities). These are processes occurring over a t^4, which have created the conditions for the emergence of cultural ecosystems for human cognition (Hutchins, 2014). Of course, processes occurring over t^1, t^2, and t^3 determine the dynamics of joint remembering in these complex systems too. Figure 1 shows how timescales complement each other in synchronic and diachronic terms. Further memory research will go beyond the analysis of joint remembering over individual timescales. It will need to integrate more controlled laboratory studies with richer observations of processes of joint remembering in natural settings, bringing experiment and ethnography together in the attempt to explain how these diverse processes are integrated in a synergistic fashion, as happens when people remember with other people in their everyday lives.

Acknowledgements

We thank two anonymous reviewers for their invaluable feedback on an earlier version of this manuscript. We gratefully acknowledge the support of the Swiss National Science Foundation (Ambizione grant PZ00P1-154968), the European Commission (Marie Curie IEF grant P7-PEOPLE-2012-IEFMC-IEF 326885) and the Australian Research Council (Discovery Project DP120100187).

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