Exploring cognitive development through the analysis of interactive repair strategies as a marker of coordination in joint actions

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Abstract

Human language is a unique cognitive capacity. This ability plays a pivotal role in our social interactions, notably enabling a high level of coordination in our joint actions through communication. Often, without even realizing it, we constantly synchronize and coordinate not only through speech but also through gestures and gazes. This allows us to establish a common ground, facilitating the resolution of obstacles in our social interactions. Indeed, this capacity for coordination helps minimize misunderstandings and optimize joint actions, thereby enhancing our interactions. However, discontinuities and misunderstandings can still arise in our conversations. Hence, we have developed repair strategies to resolve them as soon as they emerge. In this article, we aim to deepen our understanding of how this capability is acquired and its relation to our coordination abilities.

To achieve this, we conducted an experiment involving participants from different age groups—two groups of children, one aged between 4 and 5 years and the other between 6 and 7 years, and a group of adults—where pairs worked together to build various LEGO models under different conditions. These conditions included one where participants could see each other and another where they were separated by a curtain, isolating verbal communication. We analysed the conversations during these interactions, identifying various instances of interactive repairs and categorizing them by specific language characteristics. Our statistical analysis highlighted the significance of this capability in language and clarified its connection with other language features.

Our results notably indicate a difference in the ability to coordinate between both children's groups and the adult group, which is reflected in the variation of repair strategies employed. This suggests not just a cognitive gap between children and adults but also a divergence in how these groups approach the resolution of misunderstandings and coordination challenges in task-oriented conversations. Furthermore, our findings reveal a developmental progression in cognitive abilities and repair strategies between the age of 4 and 7 reflected by a greater efficiency of the interactive repairs in older children. This difference suggests a significant developmental progression in how children develop the cognitive abilities and communication strategies necessary for effective coordination and problem-solving within this age range. These observations underscore the critical role of interactive repairs in the study of joint activities, highlighting their importance in understanding cognitive development and coordination capabilities

Keywords : Joint action; Interactive repair; Common ground; Communication; Coordination; Language; Shared intentionality

Introduction

The Evolution of Human Language

The evolution of human language is a fascinating phenomenon that reflects the complexity and richness of our cognitive capacity. From the earliest utterances of humanity to the emergence of structured and diverse linguistic systems, language has played a central role in the development of our societies and cultures serving not only as a key repository but also as the primary mediator of collective knowledge in our species (Kirby & Tamariz, 2021).

The compositional quality of human language facilitates the generation of a limitless variety of sentence constructions. This capacity to form sentences with subjects, verbs, objects, and tense recognition, distinguishes human language from other animal communications, highlighting its uniqueness in expressing complex thoughts and concepts (Pagel, 2017).

Despite extensive research, the exact origins of language remain elusive, with debates on whether it emerged suddenly or evolved gradually. Theories range from language evolving from non-human primate communication systems to unique human traits, with some views considering language as innate and others as a cultural acquisition (Chomsky, 1996; Tomasello, 1996). However, recent advancements in scientific studies have led to a better understanding of language origins. Techniques to study animal behaviour, analyse fossil records, map genomes, and model evolutionary processes have provided substantial evidence, moving the field beyond speculation (Hauser et al., 2014).

Although the detailed history of language evolution may always be partly enigmatic, it's highly probable that the human ability for language developed from a genetic substrate found in the last shared ancestor of humans, chimpanzees, and bonobos. This development likely occurred through the gradual accumulation of genetic modifications over the past 6 million years (Fisher & Marcus, 2006). Certain cognitive abilities that are observable in chimpanzees and bonobos today—and that probably existed in this common ancestor—include the intelligence for problem-solving, the ability for cultural innovation and learning, and a rudimentary theory of mind, which involves understanding that others have their own mental states (Horner & de Waal 2009; Call & Tomasello 2008; Seyfarth & Cheney 2014).

Speech is the main vehicle for human language and a distinctive trait of our species. It is underpinned by a sophisticated yet comprehensible set of processes involving vocal and motor coordination, auditory perception, and neural functions which enable us to encode our thoughts into sound. This capacity, setting us apart from other primates, evolved from organs originally developed for basic functions like eating and breathing. While nonhuman primates possess similar organs, they lack the sophisticated neural control we have for the lips, tongue, and vocal apparatus (Fitch, 2000). However, the skill of vocal sound imitation is not solely a human trait but is also observed in a varied range of species, including numerous bird species, most marine mammals, elephants, and some types of bats which suggests a convergent evolution of this ability across various vertebrates (Fitch, 2018). Animals can communicate in diverse ways, including through scents, visual signals, and vocal sounds. But, despite these complex communication methods, training animals to use human language has consistently achieved only limited success (Stangor et al., 2019).

In comparing human and animal communication, we find that while animals communicate through learned behaviors and signals, the intricacy of human language is far more advanced. Humans not only use language to convey basic needs or emotions but also to express complex concepts, engage in abstract thinking, and share rich, cultural stories and knowledge. This complexity is rooted in our ability to understand and infer meaning from context, a skill that is nuanced and sophisticated in humans. Moreover, human language is dynamic and continually evolving, capable of creating new expressions and adapting to new circumstances. This ability to innovate linguistically is largely absent in animal communication, which tends to be more fixed and limited to immediate contexts. The cognitive depth of human language, with its layers of meaning, subtlety, and the capacity for creativity, marks a significant departure from the more straightforward, less varied communication forms found in the animal kingdom. This makes human language a unique, highly developed tool for interaction and expression, distinguishing our species in the realm of communication.

In comparing human and animal communication, it is observed that while animals communicate through learned behaviors and signals, the complexity of human language is far more advanced (Oller & Griebel, 2014). Humans use language not only to convey basic needs or emotions but also to express complex concepts, engage in abstract thinking, and share rich cultural stories and knowledge (Ptitsyna, 2021). This complexity is rooted in our ability to understand and infer meaning from context, a nuanced and sophisticated skill in humans (Benazzo, 2009). Furthermore, human language is dynamic and constantly evolving, capable of creating new expressions and adapting to new circumstances (McCowan & Doyle, 1999). This capability for linguistic innovation is largely absent in animal communication, which tends to be more fixed and limited to immediate contexts. The cognitive depth of human language, with its layers of meaning, subtlety, and capacity for creativity, marks a significant departure from the simpler and less varied forms of communication found in the animal kingdom (Ptitsyna, 2021). This makes human language a unique and highly developed tool for interaction and expression, distinguishing our species in the realm of communication.

Biological perspectives on language evolution primarily consider how human language capabilities relate to those in the animal kingdom, focusing on individual language aspects. In contrast, cultural approaches highlight the significance of social interaction and learning in the development of language, examining how languages evolve within populations under cultural influences. These cultural accounts analyze language behaviour and structure as the main subjects of language evolution research, rather than concentrating on a specific language faculty, suggesting that language evolution is significantly influenced by cultural interactions and the learning biases of individuals (Cuskley, 2020). Proponents of this viewpoint often refer to the idea that language evolves and adapts to the selective pressures imposed by learners (Christiansen & Chater, 2008) and thus, for a language to endure and be transmitted to future generations, it needs to be sufficiently learnable by both speakers and signers (Cuskley, 2020).

Ultimately, the evolution of human language emerges as a fascinating phenomenon that relies on a symbiosis between biological and cultural mechanisms. This duality reflects our shared genetic heritage and our unique ability to transmit and transform knowledge across generations, thus demonstrating that language is not only a product of our biology but also a reflection of our cultural and social interactions.

Language Development

Both environmental factors and human child's inherent biological capabilities are acknowledged as key contributors to the process of language development (Rowe &

Weisleder, 2020; Stangor et al., 2019). Research has thoroughly demonstrated that newborns are responsive to sound frequencies typically used in human speech and exhibit a pronounced affinity for verbal sounds suggesting a biological predisposition to recognize and interpret signals related to human language (DeCasper & Fifer, 1980; Slater, 1998). Moreover, successful language acquisition appears to depend on various developmental stages. A child not exposed to language learning from an early age may risk losing the ability to learn it at all beyond a certain point (Cayea, 2006; Rymer, 1993; Mayberry et al., 2002). Indeed, the capacity to develop neural connections associated with language seems to be more conducive at a young age, likely due to the fact that the brain's plasticity diminishes with age (Stangor et al., 2019).

Language development seems to begin even before birth, with foetuses responding to sounds from outside the womb. Indeed, research indicates that the foetus, around 4 weeks before birth, already has the necessary bottom-up processing machinery for extracting speech features in the bilateral superior temporal and inferior frontal cortices (Gervain, 2018; Skeide & Friederici, 2016). This early processing capability suggests that the development of language comprehension in children precedes their ability to produce language. Infants demonstrate a preference for their mother's language shortly after birth (Moon et al., 1993) and recognize patterns of their native language (Saffran et al., 1996). At around six to eight weeks of age, babies begin to produce a variety of vocal sounds, including vowel-like noises, cries, and squeals to help them practice (Stangor et al., 2019) and by around seven months, infants engage in babbling, an early form of vocal practice that evolves to incorporate the specific sounds of the language they are being exposed to by their first birthday (Vihman, 2017; De Boysson-Bardies et al., 1984). Babbling could also facilitate language development by organizing the social interactions in which infants experience contingent feedback from caregivers (Albert et al., 2018). This capacity typically occurs for a period of 6–9 months and gradually diminishes as the child begins to utter their first words (Harley, 2001). By the end of the first year, a general sense of the prosodic, phonotactic, and coarticulatory regularities of the ambient language is acquired (Vihman, 2014).

By their first birthday, infants not only start associating words with objects but also demonstrate the ability to access and categorize lexical items. The interval from 18 to 30 months is characterized by a remarkable expansion in vocabulary and out-of-context word comprehension. During this phase, toddlers start to construct simple sentences and employ language as a tool for inquiry, correlating vocabulary growth with a burgeoning grammatical structure (Rosselli et al., 2014; Bates & Goodman, 1997). During this first year, the ability to imitate speech also plays a key role in language acquisition (Gathercole, 2006). Around age two, children have a vocabulary of several hundred words (Stangor et al., 2019) and begin applying morphosyntactic knowledge to evaluate the grammatical compatibility of adjacent phrase categories (Skeide & Friederici, 2016). Advanced language processing, including the understanding of semantic and syntactic relations, emerges around age four and full specificity in processing complex syntax is not reached until after age 10 (Skeide & Friederici, 2016; Rosselli et al., 2014). From 3 to 5 years old, children face challenges with underextensions, overextensions, and begin understanding metaphors. As they grow into the 6 to 10 year range, they distinguish word meanings more precisely and appreciate the nuances in language through puns and metaphor (Khalaf, 2020).

Paralinguistic methods like eye gaze and vocalizations also play a role in the language acquisition process. Before the first year, these methods facilitate a basic exchange of meanings, allowing the initiation of proto-conversations with others (Donnelly & Kidd, 2021;

Bruner, 1975; Snow, 1977). Closely before their first birthday, infants begin to engage in gaze following during their interactions (Brooks & Meltzoff, 2005), which can aid in better understanding the subjects of a conversation. They start to use gestures, often by pointing to objects around them, between 9 and 12 months of age and continue doing it alongside words even after they start speaking (Bates, 2014). These early gestures offer a means for children to communicate about things they cannot yet express verbally, providing a way to refer to objects before they have the words for them. Indeed, gestures and simultaneous gesture–speech combinations seem to play a facilitating role in early language development (Iverson & Goldin-Meadow, 2005; Crais et al., 2009; Igualada et al., 2015). At the age of five, children show a refined ability to adjust their gestures according to their listeners' needs (Alibali & Don, 2002) and are capable of discerning illocutionary intent, understanding the implied meaning behind what is said (Khalaf, 2020). At one to two years old, children start engaging in conversational turn-taking (Casillas et al., 2016). This process allows them to receive feedback, adopt more complex coordination methods, and test language hypotheses. Achieving appropriate timing in turn-taking takes years and "*managing adult-like entries into ongoing exchanges may not be achieved until age six or later*" (Casillas et al., 2016), but once mastered, it propels them into the realm of rich and nuanced conversation. Such joint attention skills in early childhood are associated with subsequent language development (Kristen et al., 2011).

Conversational Dynamics : Coordination in Joint Actions

Humans frequently engage in coordinated activities with others, from simple tasks like moving furniture together to more intricate ones like playing team sports or musical performances. Such activities are referred to as 'joint actions' (Vesper et al., 2016; Sebanz et al., 2006). They involve coordinating our movements and taking decisions with others in time and space to alter our surroundings, enabling us to achieve goals that are often unattainable individually (Heesen et al., 2017). To achieve this, high levels of coordination capabilities are required . This is possible through an exchange of signals in real time that help partners to adapt to each other (Goffman, 1981). For instance, in joint actions primarily conducted through verbal communication, such as everyday conversations, speakers tailor their speech to convey their intentions (Grice, 1975) and aid in their comprehension, while recipients demonstrate their understanding of these intentions (Clark & Schaefer, 1989). Similarly, in joint actions that involve physical activities, like building Lego models, participants perform actions in a manner that is visible and informative to their partners (Clark & Krych, 2004), and they also pay attention to their partners' actions to gather information (Vesper et al., 2016). This process is known as grounding and is achieved through signal exchanges that often occur incidentally or implicitly alongside the primary conversation (Clark & Schaefer, 1989). Grounding, therefore, is the mechanism through which intersubjectivity (Merleau-Ponty, 1962) or shared intentionality (Bratman, 1992; Tomasello & Carpenter, 2007) is established (Heesen et al., 2017). This grounding process can be achieved through the use of backchannels. Such utterances are used to indicate continuous attention, understanding, or agreement (Goodwin, 1986; Yngve, 1970), and can appear as nonverbal signals (like nods, smiles, or eyebrow raises), simple verbal affirmations (examples include "mm-hmm," "yeah," "oh really"), or more involved actions such as finishing the turn of another speaker in a conversation (Tolins et al., 2017). They are critical to the success and continuation of coordinated verbal activities (Tolins et al., 2017). Backchannels are also crucial in managing transitions within and across different levels of a project hierarchy. They facilitate navigation through joint projects by marking both vertical transitions (entering and exiting projects or subprojects) and horizontal transitions (continuing within a project). This use of backchannels as project markers in dialogue is integral for coordinating and streamlining project activities, enhancing both understanding and efficiency in project management (Bangerter & Clark, 2003).

The attributes of human joint action can be presented as manifestations of a distinctly human repertoire of skills and inclinations for social interaction, termed the "interaction engine" (Levinson, 2006b). This includes particular communicative skills like the use of multimodal signals (Levinson & Holler, 2014), as well as the exchange of roles between speakers and listeners in conversations (Levinson, 2016) and encompasses unique cognitive abilities like shared intentionality (Levinson, 2006a). Collectively, these components of the interaction engine could facilitate a kind of "cognition-for-interaction" (Levinson, 2006a) that operates independently of language. Nonetheless, language has developed into a major tool for coordinating joint actions among humans (Heesen et al., 2017). This theory then suggests that our advanced communication system evolved primarily as an adaptation to the challenge of coordinating collaborative actions (Heesen & Fröhlich, 2022, Rossano et al., 2022).

Joint actions, therefore, primarily involve significant coordination among individuals, which is particularly manifested through the use of cognitive and language tools. For instance, during conversations, we instinctively coordinate with each other to seamlessly take linguistic or conversational turns, ensuring a fluid exchange of ideas and thoughts. When one speaker hands over the speaking role to another, they collaboratively strive to reduce both overlapping speech and pauses between their turns. To accomplish this, speakers collaboratively manage the timing of each person's speech by predicting when the current speaker will finish and proactively preparing their response in order to take over the conversation at the right moment. Despite the complexity of this coordination challenge, adults excel at initiating their turns, with average response times of around 200 milliseconds (Casillas et al., 2016; ten Bosch et al., 2005; de Ruiter et al., 2006; Sacks et al., 1974). Proto-forms of turn-taking emerge before spoken language, initially appearing between 11 and 18 months and continuing to develop up to the age of 2 to 3 years (Golinkoff, 1986; Alexander et al., 1997; Casillas et al., 2016). Children start to smoothly join in multi-party conversations like adults around age six (Ervin-Tripp, 1979). Before this age, they are learning to pay attention to the speaker, guess when the speaker will finish, and get their own response ready, all to speak right after the current speaker stops (Casillas et al., 2016). Children's response latencies can be significantly longer than adults, up to ten times more. In comparison to adults, in child-child conversation, the typical response time for three-year-olds falls between 1.1 and 1.8 seconds, while for five-year-olds, it ranges from 0.8 to 1.5 seconds (Casillas et al., 2016; Lieberman & Garvey, 1977; Garvey & Berninger, 1981).

This fundamental component of communicative interaction is an ubiquitous characteristic of human language (Stivers et al., 2009), and it likely imposed significant constraints on language evolution. Indeed, the processes of spoken language probably evolved to cope with the considerable time pressure that the structure of conversation exerts on speakers (Donnelly & Kidd, 2021).

Additionally to the turn taking process, coordination in joint activities could also be achieved through alignment of behaviours (Rossano et al., 2022), significantly contributing to the effectiveness of joint actions (van der Wel et al., 2021). Also referred as synchrony, such a behaviour manifests through various aspects of daily conversations (Fusaroli & Tylén, 2016).

As participants in a conversation hear each other using specific words, for instance, they become inclined to use those same words again. This pattern is not limited to vocabulary alone and also extends to the syntax and semantics of conversations, resulting in a form of unconsciously linguistic alignment (Fusaroli & Tylén, 2016). Additionally, it is believed that this alignment plays a crucial role in enhancing the performance of tasks undertaken jointly (Dideriksen et al., 2019). Linguistic alignment can also be observed in tones of voice, accents and speech rates (Louwerse et al., 2012; Neumann & Strack, 2000; Giles & Powesland, 1975; Webb, 1969).

Such a synchrony can also be perceived in non-verbal aspects like gestures, facial expressions, body posture, head movements, emotions or mood (Wynn & Borrie, 2022; Latif et al., 2014; Louwerse et al., 2012; Neumann & Strack, 2000; Shockley et al., 2003; McHugo et al., 1985). During collaborative tasks, such as assembling puzzles, people tend to synchronize their "postural sway" and share similar positions. This phenomenon, observed in various studies, highlights the innate tendency of individuals to align their physical movements and postures when working together on a common task (Louwerse et al., 2012; Shockley et al., 2003).

All these mechanisms facilitate our coordination, which is essential during joint activities. They contribute to making our speech more fluid and enhance mutual understanding between two interlocutors engaged in a conversation. However, even with processes to make conversations smoother and more efficient, errors and misunderstandings often occur, sometimes without us even realizing it. Fortunately, we have developed the ability to fix these errors.

Repair Strategies in Conversation and their Role in Coordinating Joint Actions

Human conversations, regardless of language, often encounter misunderstandings, a typical trait in both spoken and signed languages (Dingemanse et al., 2015; Safar & de Vos, 2022). These misunderstandings could disrupt the shared knowledge or common ground negotiated by individuals during conversations and which is crucial for coordinating joint activities (Tolins, 2017; Brennan, Galati, & Kuhlen, 2010). To prevent this and maintain a shared knowledge, our communication system has developed a crucial repair mechanism, allowing for the correction of miscommunications. This capacity for real-time repair, a universal feature across languages, is also acknowledged as a part of the human interaction engine (Levinson, 2006b), thereby forming a component of a suite of human cognitive and behavioural traits which are crucial for facilitating complex forms of cooperation (Heesen et al., 2022) and coordination in joint activities.

Repair mechanisms significantly enhance the resilience of communication against disruptions, noise, and breakdowns (Heesen et al., 2022). When issues related to speaking, hearing, or understanding emerge in a conversation, participants actively bring them to attention and collaboratively work to resolve them, often pausing the natural flow of the dialogue. This concerted effort underlines the high importance of repair in interactions. The involved parties focus intensely on resolving the issue until common ground is re-established. Such a process not only ensures the smooth continuation of the conversation but also sheds light on the ways participants perceive and address communication challenges (Albert & de Ruiter, 2018; Schegloff et al., 1977). Joint action offers a valuable perspective for understanding how individuals collaboratively create a mutual state of togetherness and this collaborative creation is particularly noticeable in repair situations, where the repair process is often a joint effort between the recipient and the initiator (Heesen et al., 2022). Furthermore, a study by Colman and Healey (2011) found that repair occurrences are more frequent in task-oriented conversations, where precision in mutual understanding is highly demanded (Dideriksen et al., 2019).

However, repair may assume a range of linguistic forms and exhibit varying levels of specificity in the feedback provided to the interlocutor (Dideriksen et al., 2019). There are two primary types of repair mechanisms. The first one is called self-initiated repair and initiated by the speaker who originally made the error :

A : *Can you give me the re- the blue pen please ?*

The speaker who produces the error repairs it within the same TCU (turn constructional unit) before anyone else has a chance to take a turn (Albert & de Ruiter, 2018). This type of repair is the most used in conversations (Schegloff et al., 1977).

The second type is called other-initiated repair or interactive repair (Dingemanse & Enfield, 2023) and in this case, the repair is initiated by a conversation partner other than the speaker (Schegloff et al., 1977). They can be described through a sequence of three interactional turns : the repair initiation by the recipient at turn ‘T0’, related to another’s prior turn ‘T−1’ and the provision of a solution for the repair in the subsequent turn, labeled as ‘T+1’ (Dingemanse et al., 2016) :

A : *Can you give me the red pen please ?*	(Trouble source : T-1)
B : *You said the blue one ?*	(Repair initiation : T0)
A : *No, the red one please*	(Repair solution : T+1)

Other-initiated repair typically happens in the next available slot as soon as a different speaker gets a turn in the sequence. When a recipient initiates the repair, it highlights the original speaker's talk as a trouble source and opens up a chance for either the recipient or the initial speaker to offer a solution to the issue (Albert & de Ruiter, 2018). Interactive repair requires collaboration between individuals to clear up misunderstandings, in contrast to self-initiated repair, where a person independently rectifies their own mistakes (Dingemanse & Enfield, 2023).

In the context of other-initiated repairs, it is often observed that there is a lexical and syntactic repetition (Fusaroli et al., 2017; Jefferson, 1972; Sacks, 1992). A cross-linguistic analysis of informal conversations revealed that nearly half (48%) of all turns initiating repair involved repeating a part or the entirety of the preceding turn, emphasizing the crucial role of other-initiated repair in facilitating interactive alignment (Dingemanse et al., 2015). Additionally, even though they are less frequent than self-initiated repairs, other-initiated repairs remain very common in natural conversations, with an average occurrence of once every 1.4 minutes (Dingemanse et al., 2015).

This study focuses on other-initiated repairs, wherein Dingemanse et al. (2015) outline three fundamental formats of repair initiators: open request, restricted request, and restricted offer. These repair initiator types range from least specific (open request) to most specific (restricted offer) in terms of the information they provide about the communicative trouble and the possible solution. Open requests are general, signalling an understanding problem without specifying its location (e.g., ‘What?’, ‘Huh?’), usually leading to repetition for clarification. Restricted requests pinpoint a specific part of the trouble source, seeking its specification or clarification (e.g., ‘Who?’, ‘Which one?’), with the speaker typically responding with focused repetition or clarification. The most specific, restricted offers, involve the listener proposing a candidate understanding of the trouble source, seeking confirmation from the speaker (e.g., ‘The blue one?’), thereby placing more interactional responsibility on the listener for the repair solution. People tend to opt for the most specific type of repair, a principle that reduces effort for both the individual tasked with correcting the issue and for the dyad as a social unit. If a particular repair approach is unsuccessful, participants usually escalate to more effective formats of repair initiators until the issue is fully resolved (Dingemanse et al., 2015; Albert & de Ruiter, 2018).

However, repair initiations in communication can utilize various modalities, including non-verbal cues (Holler, 2022). These can range from a noticeable lack of response such as 'freeze-looks' (Floyd et al., 2016; Manrique, 2016; Manrique & Enfield, 2015; Levinson, 2015) to body movements (Skedsmo, 2020), puzzled facial expressions like eye-widening or head tilting (Seo & Koshik, 2010), and gestures like cupping the hand behind the ear (Mortensen, 2016). The form and choice of these repair initiations are tailored to the specific type of communicative issue encountered, addressing perceptual disturbances and disparities in attention, knowledge, or understanding (Heesen et al., 2022).

When a repair is initiated, either a part or the entirety of the problematic turn is often lost due to communication issues, necessitating its restoration in the repair sequence. The collective burden of these temporary interruptions in conversation flow does not exceed the initial cost of the trouble source turn. This serves as another illustration of the principle of least collaborative effort, resulting in repair sequences that are both efficient and cost-effective (Dingemanse et al., 2015).

Furthermore, the cost of conducting the repair is shared between participants B and A in a way that is predicted by the type of repair initiator used. Participant B, in choosing the repair initiator based on the principle of specificity, tends to bear as much of the cost as possible. This behaviour of B, selecting the most specific repair initiator available, demonstrates altruism and results in minimizing the joint cost (Dingemanse et al., 2015).

These principles of specificity, conservation, and division of labour uncover a shared aspect of prosocial behaviour that underpins the functioning of the repair system across all examined languages (Dingemanse et al., 2015).

Additionally, interactive repair not only employs but also demonstrates the inherent reflexivity of language, which is its capability to self-reference and self-regulate. It is also built upon and integrates methods for social accountability, providing interaction participants with ways to hold one another accountable and ensuring that their conversations remain on track (Dingemanse & Enfield, 2023).

The observable aspects of repair in communication not only reflect deeper processes like self-monitoring and other-monitoring, but also cooperative motivations such as joint commitment (Gilbert, 2017) and a focus on understanding and sharing intentions (Tomasello et al., 2005). Interactive repair involves flexible collaborative action from both the signaller and the receiver. It includes monitoring and responding to any discrepancies in attention, knowledge, and comprehension, signalling these gaps during communicative issues. This process also demands coordination in itself, putting the ongoing activity on hold to collaboratively address the problem. Therefore, this dynamic process has been described as one of the places where theories of mind come to the surface (Dingemanse et al., 2015).

However, it's important to note that, despite the critical role of repairs in facilitating joint actions, maintaining shared knowledge, and contributing to the emergence of theories of mind, these cognitive abilities operate independently. Each ability follows its own unique developmental trajectory, indicating a complex interplay between cognitive development and social interaction processes.

Developmental Pathways in Joint Activities and Conversational Repairs

Fundamentally, joint activities necessitate joint attention, which involves understanding what others can perceive and predicting their actions based on current and past behaviours. This ability is crucial to determine the actions needed to achieve a shared goal (Rossano et al., 2022; Sebanz et al., 2006). This could require a matching of plans and subplans (Bangerter & Clark, 2003; Bratman, 1992) which on the surface seems to pose major cognitive demands that some researchers sould claim to be observable in children only at 5 years old (Milward & Kita, 2014). Furthermore, joint actions, like repair strategies, require theory of mind abilities to understand the perspective of the person with whom one is attempting to coordinate (Sebanz et al., 2006; Dingemanse et al., 2015). However, these cognitive abilities in children continue to develop significantly beyond the ages of 5 or 6 years (Wellman, 2017).

However, children show social interest towards each other and appear capable of participating in joint activities starting from about 12 months old (Carpenter, 2009). But, before reaching 18 months, children's social interactions with their peers are relatively rare and tend to lack coordination (Brownell & Brown, 1992; Eckerman & Peterman, 2001). Before they fully develop speech, children use imitation of their peers' nonverbal actions as a key behavioural method to achieve coordination (Eckerman et al., 1989). Between the ages of 20 and 24 months, there is an increase in cooperative play, including imitative games, among peers. This period also sees the development of more advanced skills in initiating, sustaining, and coordinating interactive activities (Eckerman et al., 1989). From 24 to 30 months, children demonstrate reliable cooperation in problem-solving tasks, a capability not typically found in younger children (Brownell & Carriger, 1990). During their third year, children's social understanding and language about themselves and others evolve and they care more about social norms and game rules (Rakoczy & Schmidt, 2013; Rakoczy et al., 2008). It is at this stage that they start participating in social games in a more coordinated and cooperative manner (Brownell et al., 2006; Eckerman & Didow, 1996; Verba, 1994). By considering their partners' intentions and closely observing the timing and sequence of both their own and their partners' actions, children can effectively adapt their behaviour to successfully achieve shared objectives (Barresi & Moore, 1996; Brownell et al., 2006; Smiley, 2001). Regarding the cognitive abilities for shared intentionality, children from 12 months display a willingness to communicate and share attention through gestures like pointing (Liszkowski et al., 2006). They also start to understand and participate in role reversal (Carpenter et al., 2005). By 18 months, they try to re-engage peers in interrupted activities (Warneken et al., 2006) and assist others in achieving goals (Warneken & Tomasello, 2006). Finally, from 14 months, children are already capable of shared intentionality, and by age three, they become aware of the nuances of joint commitments and the related responsibilities in joint actions (Kachel et al., 2017; Gräfenhain et al., 2013; Gräfenhain et al., 2009).

In the realm of child language development, the role of repairs is of paramount importance. From the end of their first year, children start to monitor their own speech and begin initiating repairs when necessary, showing a tendency for self-repair as do adults (Clark, 2020). Additionally, even in their first year, young children design their gestural communication to reflect an awareness of others' attentional states (Rodrigues, 2021), engaging in self-initiated repairs like repeating or revising communicative acts unprompted. This behaviour reveals their emerging self-monitoring abilities (Scollon, 1976; Forrester & Cherington, 2009).

However, the ability to fully engage in interactive repairs takes more time to emerge. In these early stages, children experience repair alongside their initial communicative attempts, with caregivers repeating, reformulating, and recontextualizing their utterances to facilitate the development of social engagement (Dingemanse & Enfield, 2023; Taylor & van den Herik, 2021; Clark, 2020). From early in their second year, children also react to requests for clarification initiated by others, addressing both open and restricted requests (Clark, 2020). They may repeat their statements more loudly or modify their original utterances, such as by including grammatical morphemes or altering the words and their order (Clark, 2020). By the age of three, children start to express their own uncertainties and ask for explanations, often using open requests like 'huh?' and 'what?' in English (Clark, 2020; Garvey, 1977; Garvey, 1979).

The high frequency and explicit metalinguistic nature of repair could be central for early language learners in grasping the concepts of reflexivity and social accountability (Dingemanse & Enfield, 2023). These skills, instinctively used by children, extend beyond mere enhancement of pronunciation and lexicon development. Indeed, they play a crucial role in building lexical knowledge through the repetition of words and phrases (Clark, 2020; Ghazi-Saidi & Ansaldo, 2017) and acts as a metalinguistic scaffold, aiding children in the development of their lexical and grammatical abilities. Furthermore, these repairs facilitate the acquisition of pragmatic skills by demonstrating how meaning is negotiated in context, while also providing insights into morphosyntactic structure. These processes, ingrained from a very young age, illustrate how repairs contribute not only to error correction but also to a deeper understanding and overall development of linguistic competencies in children (Dingemanse & Enfield, 2023; Saxton, 2005; Soto, Tönsing & Soto, 2020). Based on one estimate, up to half of the interactions initiated by infants incorporate elements of interactive repairs (Dingemanse & Enfield, 2023; Golinkoff, 1986), underscoring the pivotal role of repair within the foundational framework of early language development (Clark, 2020; Casillas et al., 2016; Saxton, 2005). Repair mechanisms might be a distinctive human trait that has significantly influenced the evolution of language (Heesen et al., 2022).

Identifying Research Gaps

The study of interactive repairs within human language is of paramount importance. Recognized as a crucial component of the 'interaction engine', facilitating our coordination and establishment of common ground during joint actions, repair mechanisms deserve the attention they receive. However, the evolution of this linguistic tool across different stages of development remains understudied, and its role in language acquisition remains elusive.

Our primary focus is on our ability to coordinate during joint actions. Consequently, we have chosen to emphasize interactive repairs, as they demand the most coordination among participants. We are particularly interested in the significant development of cognitive abilities between the ages of 4 and 7. We hypothesize that this age range also corresponds to a critical period for the development of repair mechanisms reflecting a switch in common ground maintenance abilities.

To investigate whether a significant shift occurs within this critical age range, with increasingly efficient usage strategies as we grow, we have selected specific participant groups. These include one group comprising participants between 4 and 5 years (hereafter 'younger children') and another between 6 and 7 years (hereafter 'older children'). Additionally, we have included a group of adult participants to compare the utilization capabilities of such a tool between ages when cognitive abilities are still burgeoning and when they are fully acquired and optimized.

In this study, we have chosen a collaborative task that requires participants to collaborate and coordinate with each other. Our experiment will establish two conditions: a 'visible' condition, where participants can coordinate both verbally and non-verbally (through gestures, nods, smiles, etc.), and a 'hidden' condition that isolates verbal coordination only. This setup is designed to study the importance of verbal and non-verbal coordination and to test the different adaptive abilities of participants based on their cognitive capacities.

We have opted for task-oriented conversations because they involve a clear objective for the participants, leading to higher engagement levels compared to natural conversations. Unlike spontaneous ones, task-oriented conversations require participants to exert more effort to align with each other and demand greater coordination.

Lastly, it has been demonstrated that repairs are more frequently employed in task-oriented conversations, making it an ideal environment for studying this tool. We aim to identify a large number of repairs to better compare their rates and usage strategies.

Research Questions

In our exploration of interactive repair mechanisms among Swiss French speakers in task-oriented conversations (TOC), we aim to address several pivotal research questions. These questions are designed to deepen our understanding of how conversational repairs vary across different age groups and how they are influenced by specific language features. Our goal is to detect a correlation between the ability to use interactive repairs and increasing age, with a potential shift in capabilities among the children's groups. Below are the 3 key research questions that will guide this study:

1. How does the frequency and types of repairs vary in Swiss French across different age groups?

This segment focuses on examining the frequency and types of interactive repairs used by both adults and children who speak Swiss French. The aim is to understand how the use and complexity of repair strategies evolve from childhood to adulthood and to identify the developmental stages at which various types of repairs are acquired.

The collaborative task in our study will require a high level of coordination, and we anticipate that adults, with a better understanding of the stakes, will make greater use of interactive repairs. We expect to observe even more pronounced differences between adults and children under the "hidden" condition. This condition demands heightened levels of coordination and an ability to comprehend the information available to the person one is collaborating with. Given that children are at an age where their theory of mind is still developing, we anticipate better collaboration and coordination from the adult group in the hidden condition. Regarding the two groups of children, we also expect the older children to collaborate more effectively, employing more efficient repair strategies compared to the younger children.

Since people tend to adhere to the 'strongest initiator rule' (Clark & Schaefer, 1989), which implies choosing the most specific repair format possible within given constraints, we expect to find a more frequent use of the most effective formats of repair initiators. Specifically, we expect restricted offers to be used more frequently than restricted requests, which in turn are anticipated to be more common than open requests, regardless of the condition for each group

2. How do conversational repair strategies vary across age groups in terms of efficiency?

This section analyses how different age groups succeed in initiating and effectively concluding repairs in conversations, highlighting the evolution of repair efficiency with linguistic development. Based on the general understanding that linguistic and cognitive skills develop with age, we anticipate finding that adults are more efficient in using conversational repair strategies compared to children. Furthermore, once again, we expect to observe a correlation between the use of repair strategies and increasing age, which is why we anticipate seeing more effective strategy utilization within the older children's group.

3. How does the role of repetitions in repairs vary across age groups?

This part focuses on the role of repetitions as a tool in conversational repair, examining how their use varies between children's groups and adults and the impact of these variations on the quality of communication.

Once again, we anticipate observing a difference between the two groups of children, with potentially older children resorting to repetition less frequently. This expectation is grounded in the theory that younger children might use repetitions more as a compensatory mechanism due to their developing linguistic proficiency (Clark, 2020; Ghazi-Saidi & Ansaldo, 2017). On the other hand, adults are likely to employ repetitions more strategically, perhaps for emphasis or to ensure clarity in complex interactions.

4. How do different groups vary in their associative use of visual cues and repair initiations?

This section will explore the importance each group places on the use of visual cues during repair initiations. This will allow us to determine if different groups employ distinct strategies in their use of repairs, particularly in terms of the modalities chosen. Some groups may tend to pair repairs with gestures, while others might rely solely on verbal repairs.

Given that children's groups may be more limited in terms of vocabulary, we anticipate that the two children's groups will differ from the adult group in that they are more likely to use gestures when they struggle to find the right terms to express themselves. Once again, we also expect to observe a difference within the two children's groups, with older children being able to use repairs exclusively through the use of words, possibly in contrast to younger children.

Methods

Participants

In the initial phase of our study, conducted at the end of 2022, we recruited 84 Swiss French-speaking adults. We were able to randomly select 30 participants, forming 15 dyads for task-oriented conversations. This group, composed exclusively of native French speakers, was recruited from the University of Neuchâtel community through posters and flyers (see Appendix A), and all participants provided informed, written consent. The adult group was composed of an equal number of males and females, all native French speakers, with an average age of 22 years (SD = 2.83).

The children's groups were not directly recruited by us but were integrated into our study from a separate research project focused on backchannels among children. This collaboration allowed us to expand our participant base to include younger age groups. The children were recruited from various daycare centres in Neuchâtel, Switzerland. The recruitment process involved contacting caretakers with letters, presenting the study at daycare centres, and then sending recruitment letters to parents through these centres, all while ensuring privacy concerns were addressed. With parental consent secured, the children were recorded directly at the daycare centres. In the children's groups, gender balance was also maintained; the older group had an equal number of boys and girls with an average age of 6.73 years (SD = 0.69), while the younger one consisted of 57% males and 43% females with an average age of 5.03 years (SD = 0.56).

This integration of data from another study enabled us to compare the communication strategies across different age groups, with the experiments now including a broader demographic. The level of familiarity among participants varied significantly, ranging from pairs who were strangers to each other to those who were best friends. The research on adults was conducted by us at the University of Neuchâtel, whereas the children's data was collected by researchers working on the backchannel study, highlighting a collaborative effort to understand communication dynamics.

Procedure

Participants were arranged face-to-face (see Figure 1) within a setting designed to facilitate interaction and closely monitored using video cameras. Adult participants were provided with clip-on microphones to ensure the clarity of audio recordings, while the children's conversations were adequately captured through the camera's built-in microphones due to practical considerations. Each dyad embarked on the collaborative task of constructing a series of Lego models—10 in total—preceded by an initial model that served as a practice round to confirm their comprehension of the experimental procedures (see Appendix B & C).

Participants assumed the roles of either 'Director' or 'Builder,' with the Director having sight of a complete Lego model to be replicated, which was hidden inside a box to obscure it from the Builder's view. The Builder, on the other hand, had access to all the necessary Lego pieces for construction. The Lego pieces available to the Builder were meticulously organized and sorted by colour to maintain consistency across sessions (see Figure 2). They also included distracting blocks that were not necessary for the construction (see Appendix B & C). The roles of Director and Builder were balanced across genders to make sure that the same amount of female and male participants played each role and to avoid any gender-based bias in role assignment. For each session, the ten Lego models to be constructed were divided into two blocks of five, each corresponding to one of the two experimental conditions, either visible or hidden. In the visible condition, the Director could not only give verbal instructions but also physically indicate the necessary pieces. However, under the hidden condition, a partition screen with a curtain was used to block mutual visibility and thus, the director was limited to verbal directives only. The first five models were built under a single condition, and this condition then switched for the remaining five models, transitioning to the opposite. Although the order of model presentation remained the same, the initial condition (visible or hidden) varied from one session to another, thus ensuring an even distribution of condition order across the sessions. However, the initial model, model 0, used to confirm participants' understanding before the start of the experiment, was always constructed under the visible condition.

The children groups were given the same Lego models to build, while the adults received a different, more complex set to match their higher skill level. Each of the models presented to the children consisted of 4 Duplo block pieces, while the models in the adult group were composed of 6 pieces each (see Appendix C). Additionally, the colours of the Lego pieces had less variation and shade within the children's groups than for the adults, which contributed to making the task more suitable for each cognitive level.

After the construction of each model, participants notified the experimenter, who then checked the build for accuracy alongside the participants, thereafter resetting the models for the next instruction cycle. Uniform scripted instructions were provided to all participants to eliminate any potential bias.

The approach we adopted, especially the use of Lego construction tasks as a key component of our experiment, is inspired by a method already used in the field (Clark & Krych, 2004). Their work on monitoring addressees in task-oriented conversations provided a solid foundation for our experimental design.

A total of 45 recordings were collected, comprising 15 from each group. Of these, 15 videos per group, 8 started with the visible condition and 7 with the hidden condition. These were transcribed by two research assistants who are native speakers of French, using the program ELAN 6.4. The transcription process for all groups adhered to an identical and precise procedure, as detailed in the study's appendix (see Appendix D), ensuring consistency in the data processing. The transcription is utterance-based, with each turn defined as a vocal production by one speaker that did not contain a pause longer than approximately 2 seconds. A turn would continue as long as the participant was speaking, even if they were interrupted by their conversational partner.

Due to time constraints, our analysis focused on conversations during the construction of models 2, 3, 7, and 8, covering two models each in the visible and hidden conditions. In total, 180 model constructions were analysed (4 per session), revealing 775 interactive repairs. Among these, 289 repairs were attributed to the adult group, 213 to the older children's group, and 273 to the younger children's group. Within these repairs, the adult group accounted for 438 instances of interactive repair initiations, the older children's group for 401, and the younger children's group for 546.

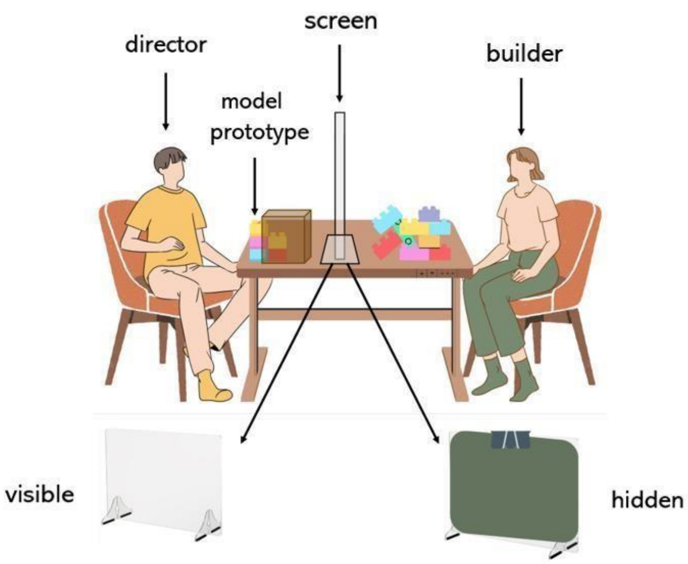

FIGURE 1 : SET-UP OF THE EXPERIMENT (MOROZOVA, N., STOLL, S., & BANGERTER, A. (2025). CONVERGENT EVOLUTION OF PROJECT MARKERS: UNIVERSAL STRATEGIES OF JOINT ACTION COORDINATION [SUPPLEMENTAL MATERIAL] [MANUSCRIPT IN PREPARATION]. DEPARTMENT OF COMPARATIVE LANGUAGE SCIENCE, UNIVERSITY OF ZURICH, ZURICH, SWITZERLAND.)

FIGURE 2 : PICTURE OF THE LEGO PIECES AVAILABLE TO THE BUILDER IN THE ADULT GROUP

Data analysis

We analysed orally expressed repair initiations in conversations, using a coding scheme primarily based on the framework from Dingemanse et al. (2016). Following this scheme, we segmented the conversational repairs into three parts: (T-1) for the turn containing the trouble source, (T0) marking the initiation of the repair, and (T+1) indicating the potential conclusion of the interactive repair. Therefore, it is important to note that each (T-1) represents an interactive repair that could involve multiple initiations before the repair is successfully concluded (see Appendix E).

The categorization of repair initiations was guided by Dingemanse et al. (2015). This involved classifying instances such as open requests, restricted requests, and restricted offers. A key part of our analysis focused on lexical alignment.

As repetitions could play an important role in interactive repairs, we recorded instances where any word used from the onset of the trouble source up to the point of repair initiation was repeated in the repair initiation, while specifically excluding conjunctions like 'and' and 'or'. This approach led us to categorize repair initiations as either containing a repetition or not, based on whether a word from the sequence starting at the trouble source and extending to the repair initiation was repeated.

Additionally, we counted the number of words used by the builder and the director independently for each model built, providing insights into each participant's verbal contributions during the construction process. It's important to note that words used in between the distribution of each new model were not included in this count, focusing our analysis specifically on the communication during the building phase of each model.

Visual cues accompanying verbal repairs were also documented. For example, any repair initiation that involved a visual gesture, like pointing to a specific Lego piece, was classified in this category. We have also accounted for all repair initiations that include phrases like "this one?", "here?", "like this?" as they inherently require visual feedback from the recipient. In essence, we categorized all repair initiations that necessitate a response entailing visual feedback.

Another aspect of our data collection was the success rate of each model's construction. We assessed whether each model was replicated accurately (perfect replica), marking 'yes' for successful replications and 'no' for unsuccessful ones (regardless of the degree of error).

This detailed approach to data quantification allowed a comprehensive understanding of the participants' verbal communication strategies and the effectiveness of these strategies in the context of the Lego construction tasks.

Statistical tests

To address our research questions, we organized our statistical analysis to correspond with each question, ensuring a coherent and logical flow of investigation. Here's how we structured our analysis to explore each research question :

1. How does the frequency and types of repairs vary in Swiss French across different age groups?

To address the first research question regarding how the frequency and types of repairs vary in Swiss French across different age groups, we utilized two distinct statistical approaches with the Linear Mixed-Effects Regression Model and the Multinomial Regression Model. For assessing the frequency of repairs, we conducted two separate analyses using the Linear Mixed-Effects Regression Model: one model calculated the occurrences of T-1 (indicative of an interactive repair) per number of words, providing insight into the verbal density of repairs, while the other model calculated the number of repairs per constructed model, offering a perspective on the frequency of repairs in relation to the task activities. This dual analysis approach allowed us to thoroughly compare the rate of interactive repairs across different age groups, examining both the linguistic and task-oriented aspects of repair occurrences.

Additionally, we employed the Multinomial Regression Model to explore the types of repairs used across groups, focusing on open requests, restricted requests, and restricted offers. This analysis helped us to understand the preferences for specific repair strategies among different age demographics, contributing to a comprehensive view of conversational repair dynamics in Swiss French. This structured analytical framework enabled us to dissect the nuances of repair frequency and types, shedding light on the complexity of conversational repairs within task-oriented interactions.

2. How do conversational repair strategies vary across age groups in terms of efficiency?

For our second research question, focusing on the efficiency of conversational repair strategies across age groups, we analysed the number of initiations required to successfully conclude a repair. Given the variability in our data, we opted for median values rather than means to gauge efficiency. This aspect of our study utilized the calculated medians to determine which groups exhibited greater efficiency in their repair strategies, with lower median numbers of repair initiations suggesting higher efficiency. This analysis provided insights into the effectiveness of the repair processes among different age groups.

3. How does the role of repetitions in repairs vary across age groups?

To explore the third question regarding the role of repetitions in repairs across age groups, we applied a Generalized Linear Mixed-Effects Regression Model. This model allowed us to classify repairs based on whether they contained repetitions and to integrate variables such as the type of repair, group composition, experimental conditions, and gender. By doing so, we gained a comprehensive understanding of how repetitions are utilized in repairs among different age groups and how this strategy varies in its application.

4. How do different groups vary in their associative use of visual cues and repair initiations?

Finally, to address the fourth question on the variation in the associative use of visual cues and repair initiations across groups, we employed a Generalized Linear Mixed-Effects Regression Model with a binomial family. This model quantified the frequency of visual cue use, such as gestures, during repair initiation, particularly under visible conditions. Additionally, we noted instances where participants used gestures during repairs in visible conditions, even though such gestures were not effective because the participants could not see each other. This analysis allowed us to gain insights into the cognitive abilities of the different groups of participants, particularly in terms of their understanding of the information accessible to their partner, shedding light on their theory of mind.

Our analysis, conducted using R version 4.3.1, was thorough and detailed, ensuring that each research question was explored with appropriate statistical models. This structured approach allowed us to dissect the complexity of conversational repairs in Swiss French, highlighting differences and similarities across age groups in terms of frequency, types, efficiency, repetitions, and the use of visual cues in repair initiations.

Results

For practical reasons, the value "Ad" will refer to the adult group, "Oc" to the older children group, and "Yc" to the younger children group. The types of repairs will be denoted as "OR" for Open Requests, "RR" for Restricted Requests, and "RO" for Restricted Offers.

1. How does the frequency and types of repairs vary in Swiss French across different age groups?

When examining the total number of interactive repairs per constructed model (see Figure 3) in the visible condition, each group uses roughly the same number of repairs, with no significant difference between the three groups (Ad – Oc: estimate = 0.0457; SE = 0.171; z.ratio = 0.267; p = 0.7891)(Ad – Yc: estimate = -0.2672; SE = 0.163; z.ratio = -1.639; p = 0.1012)(Yc – Oc: estimate = -0.3130; SE = 0.164; z.ratio = -1.904; p = 0.0568). However, in the hidden condition, there is a difference between the adult group and the two children groups, with the adult group showing more interactive repairs in the hidden condition compared to the other groups (Ad – Oc: estimate = 0.4995; SE = 0.155; z.ratio = 3.229; p = 0.0012)(Ad – Yc: estimate = 0.2941; SE = 0.149; z.ratio = 1.970; p = 0.0489)(Yc – Oc: estimate = -0.2054; SE = 0.161; z.ratio = -1.279; p = 0.2007). We thus observe an impact of the hidden condition only for the adult group, with significantly different values between the two conditions for this group but not for the children's groups (Ad: estimate = 0.57597; SE = 0.12204; z = 4.720; p < 0.0001)(Oc: estimate = 0.12221; SE = 0.13669; z = 0.894; p = 0.3713)(Yc: estimate = 0.0146; SE = 0.1203; z = 0.121; p = 0.90343). The impact of the condition is significantly different between the adult group and the children's groups (Ad – Oc: estimate = -0.45375; SE = 0.18324; z = -2.476; p = 0.01328)(Ad – Yc: estimate = -0.56138; SE = 0.17137; z = -3.276; p = 0.00105). However, between the children's groups, the condition does not have a significantly different impact (Yc – Oc: estimate = 0.1076; SE = 0.1821; z = 0.591; p = 0.55444).

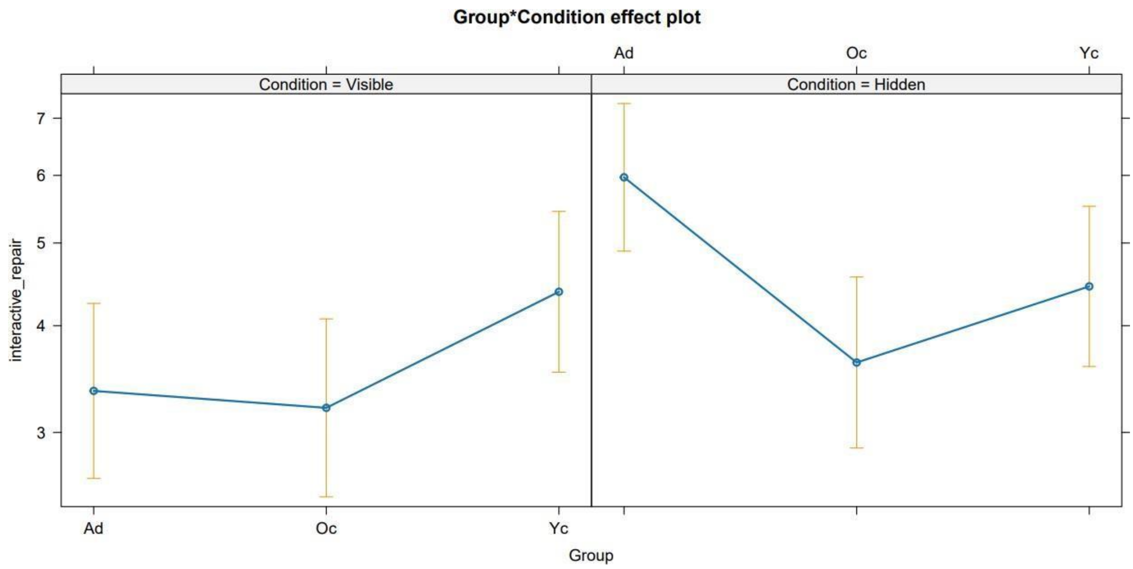

FIGURE 3 : NUMBER OF INTERACTIVE REPAIRS PER MODEL ACROSS GROUPS AND CONDITIONS (THE X-AXIS REPRESENTS THE TWO CONDITIONS AS WELL AS THE DIFFERENT GROUPS. THE Y-AXIS, MEANWHILE, REPRESENTS THE NUMBER OF REPAIRS PER MODEL)

When we now assess the number of repairs relative to the total number of words used in each constructed model (see Figure 4), in the visible condition, the values are not significantly different between the groups (Yc – Oc: estimate = 0.00104; SE = 0.0163; t.ratio = 0.064; p = 0.9489)(Yc – Ad: estimate = 0.01653; SE = 0.0163; t.ratio = 1.014; p = 0.3104)(Oc – Ad: estimate = 0.01549; SE = 0.0163; t.ratio = 0.950; p = 0.3419). Looking at the hidden condition, the values are also similar across groups with no significant differences (Yc – Oc: estimate = 0.00748; SE = 0.0163; t.ratio = 0.459; p = 0.6464)(Yc – Ad: estimate = 0.01218; SE = 0.0163; t.ratio = 0.747; p = 0.4550)(Oc – Ad: estimate = 0.00470; SE = 0.0163; t.ratio = 0.288; p = 0.7731). However, the values for the visible condition are significantly different from those for the hidden condition for the Yc and Oc groups, but not for the Ad group (Yc: Visible – Hidden: estimate = 0.00593; SE = 0.00278; t.ratio = 2.136; p = 0.0345)(Oc: Visible – Hidden: estimate = 0.01236; SE = 0.00278; t.ratio = 4.454; p < .0001)(Ad: Visible – Hidden: estimate = 0.00157; SE = 0.00278; t.ratio = 0.566; p = 0.5724). When examining the impact of the condition on the values for each group, a significantly different impact is observed only between the Oc and Ad groups (Yc – Oc: estimate = -0.006433; SE = 0.003925; t = -1.639; p = 0.1036)(Yc – Ad: estimate = 0.004358; SE = 0.003925; t = 1.110; p = 0.2689)(Oc – Ad: estimate = 0.010790; SE = 0.003925; t = 2.749; p = 0.00681).

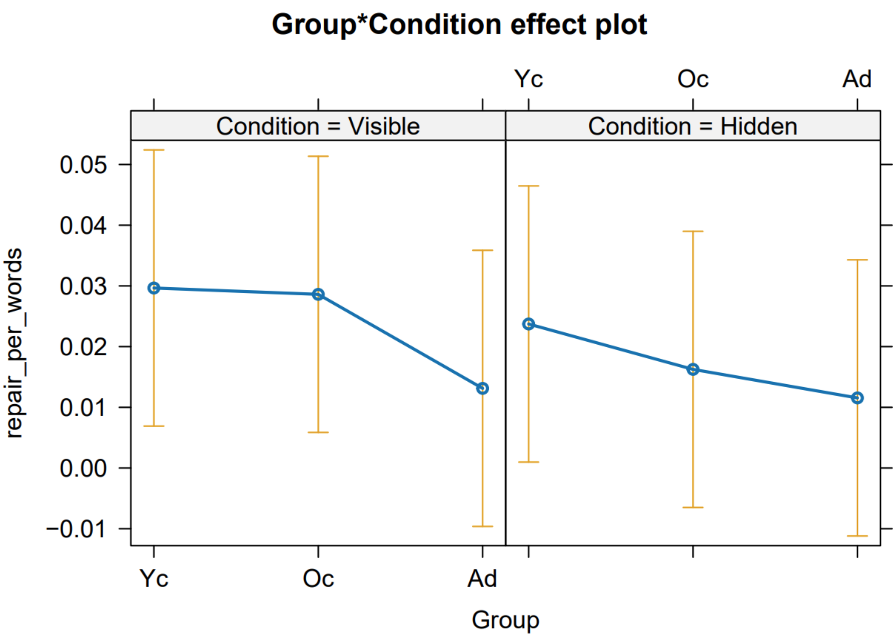

FIGURE 4 : COMPARISON OF THE NUMBER OF REPAIRS PER NUMBER OF WORDS ACROSS GROUPS AND CONDITIONS. IN THIS GRAPH, THE X-AXIS REPRESENTS THE TWO CONDITIONS AS WELL AS THE DIFFERENT GROUPS. THE Y-AXIS, MEANWHILE, REPRESENTS THE NUMBER OF REPAIRS PER NUMBER OF WORDS USED (FOR EXAMPLE, 0.03 INDICATES 3 REPAIRS FOR EVERY 100 WORDS).

To investigate the differences in repair strategies across groups, we employed a multinomial regression model. Subsequent post hoc analyses were performed to further elucidate these findings. In terms of the usage rates for the various types of repairs, across each group and condition, Open Requests (OR) are the least utilized. They are followed by Restricted Requests (RR), with Restricted Offers (RO) being the predominant strategy, as they are the most frequently employed type of repair. In the visible condition, the usage proportions for each type of repair are not significantly different between groups. That is, each group uses approximately the same proportions of OR, RR, and RO (see Figure 5).

```
repair_type = OR:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc    0.02325 0.0117  6   1.988  0.1958
 Yc - Ad    0.01589 0.0138  6   1.155  0.5188
 Oc - Ad   -0.00737 0.0110  6  -0.671  0.7878

repair_type = RO:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc   -0.08193 0.0267  6  -3.064  0.0503
 Yc - Ad   -0.00212 0.0344  6  -0.062  0.9979
 Oc - Ad    0.07982 0.0324  6   2.460  0.1074

repair_type = RR:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc    0.05868 0.0246  6   2.388  0.1177
 Yc - Ad   -0.01377 0.0322  6  -0.427  0.9058
 Oc - Ad   -0.07245 0.0309  6  -2.343  0.1247
```

FIGURE 5 : POST-HOC RESULTS FOR ALL REPAIR TYPES IN VISIBLE CONDITION. WE CAN SEE THAT IN THE VISIBLE CONDITION, THE PROPORTIONS OF USAGE FOR EACH TYPE OF REPAIR ARE NOT DIFFERENT AMONG THE GROUPS.

When examining the hidden condition (see Figure 6), it becomes apparent that the children's groups employ a greater proportion of Restricted Requests (RR) compared to the adults. Consequently, the children utilize fewer Restricted Offers (RO) than the adult group in this condition.

```
repair_type = OR:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc     0.0154 0.0198  6   0.778  0.7292
 Yc - Ad     0.0385 0.0167  6   2.302  0.1315
 Oc - Ad     0.0231 0.0160  6   1.438  0.3816

repair_type = RO:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc     0.0192 0.0430  6   0.447  0.8977
 Yc - Ad    -0.1847 0.0361  6  -5.121  0.0052
 Oc - Ad    -0.2039 0.0385  6  -5.300  0.0044

repair_type = RR:
 contrast estimate     SE df t.ratio p.value
 Yc - Oc    -0.0347 0.0413  6  -0.839  0.6948
 Yc - Ad     0.1462 0.0341  6   4.282  0.0123
 Oc - Ad     0.1808 0.0370  6   4.893  0.0065
```

FIGURE 6 : POST-HOC RESULTS FOR ALL REPAIR TYPES IN HIDDEN CONDITION. WE CAN OBSERVE THAT IN THE HIDDEN CONDITION, THE PROPORTIONS OF USAGE FOR EACH TYPE OF REPAIR VARY AMONG THE GROUPS, SPECIFICALLY FOR RESTRICTED OFFERS (RO) AND RESTRICTED REQUESTS (RR).

If we compare the ratios in visible and hidden conditions, we have the adult group maintaining similar rates between each condition, with the same proportions of repair type usage in both visible and hidden conditions. The children's groups, on the other hand, slightly increase their usage rate of RR in the hidden condition and use slightly fewer RO. However, even though the rate of RR increases at the expense of RO for the children's groups, they still use more RO in comparison to RR (see Figure 7).

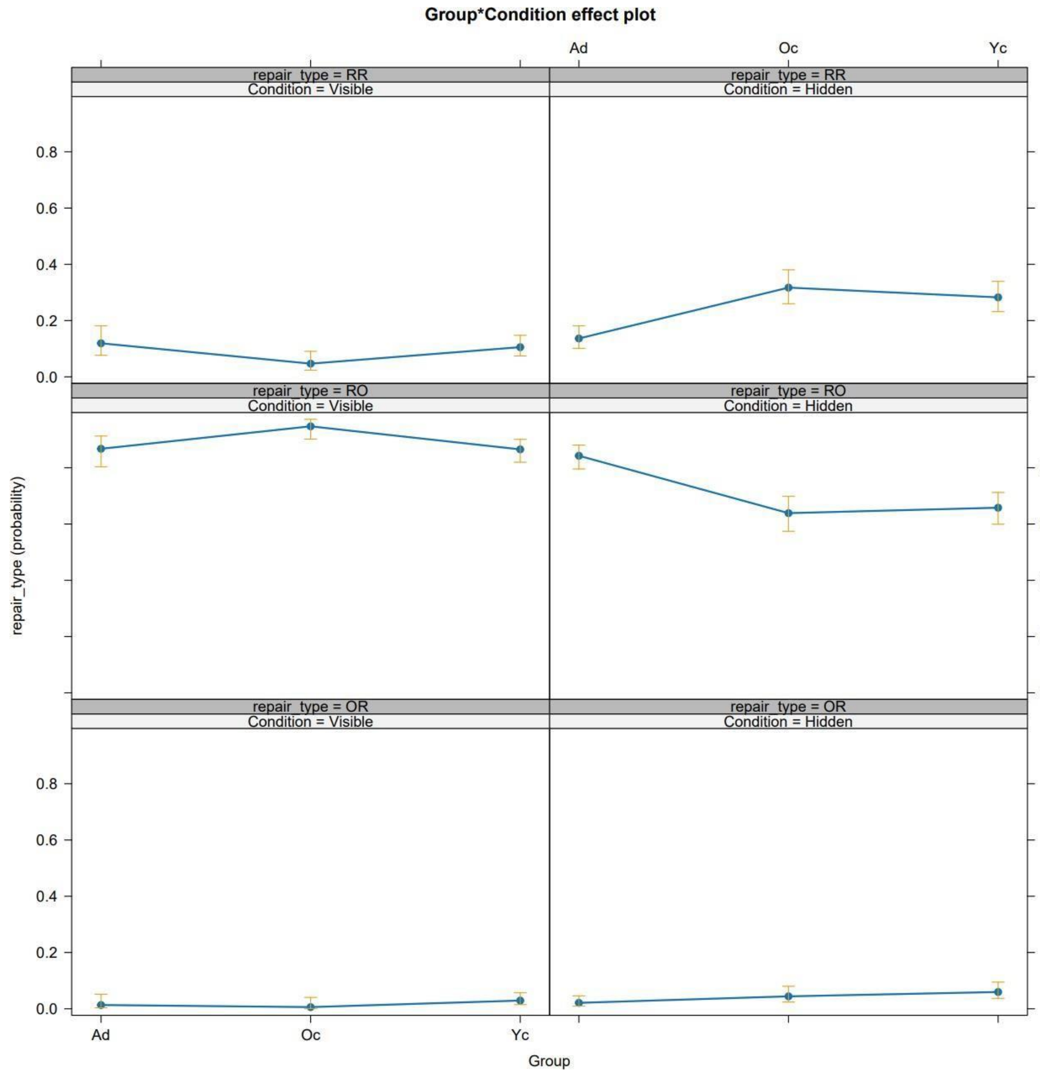

FIGURE 7 : ANALYSIS OF VARIATIONS IN REPAIR STRATEGIES ACROSS DIFFERENT GROUPS AND CONDITIONS. IN THIS GRAPH, THE X-AXIS REPRESENTS BOTH THE TWO CONDITIONS AND THE DIFFERENT GROUPS. EACH SQUARE INDICATES THE USAGE RATE FOR EACH TYPE OF REPAIR RELATIVE TO THE OTHER TYPES. (OR = OPEN REQUESTS; RR = RESTRICTED REQUEST; RO = RESTRICTED OFFER) THE Y-AXIS, ON THE OTHER HAND, SHOWS THE VALUE OF THESE RATES.

Interpretation of the results

When examining the results for the number of interactive repairs per constructed model, we observed a similar number of repairs in the visible condition across all three groups but a higher number of repairs in the hidden condition for the adult group compared to the visible condition. This reflects similar repair strategies among the groups, with an equivalent emphasis on the number of repairs in the visible condition. However, when participants are limited to using only verbal repairs in the hidden condition, individuals of different ages do not react in the same manner. Indeed, only the adult group seems to understand that the hidden condition requires more effort and necessitates participants to work harder to maintain common ground with more frequent repairs. Indeed, in the hidden condition, participants lack access to the visual cues typically available in the visible condition, making it more likely for common ground to be disrupted in the hidden condition. The results suggest that only the adult group realizes this and modifies their repair strategy accordingly to ensure that common ground is maintained by increasing the frequency of repairs.

When looking at the number of repairs per number of words used, the observed differences are almost the same. However, instead of observing a higher number of repairs per number of words in the hidden condition for adults, it is the two children's groups that have their number of repairs per number of words lower in the hidden condition than in the visible condition, while the adult group does not see its rates change between the two conditions. Again, it is evident that the children's group has not adapted its repair rate according to the condition; on the contrary, the number of repairs per number of words is lower in the hidden condition. This suggests a misunderstanding of the situation by the children who, instead of using more repairs in the hidden condition to ensure that common ground is maintained, see their number of repairs decrease. Overall, our results thus suggest non-optimized strategies for maintaining common ground within the children's groups. The two children's groups show no difference both in their rate of repairs per model and in the number of repairs per number of words used. Therefore, no difference in strategy in the frequency of repairs employed is observed. This suggests that between the ages of 4 and 7, the ability to maintain common ground remains the same and does not evolve within this age range, given that no discernible difference is observed between the two groups.

Turning our attention to the types of repair initiators used during the experiment, the findings indicated equivalent proportions across all groups in the visible condition. For each of the three groups, we observed similar ratios, with open requests being the least utilised type of repair initiator, followed by restricted requests, and restricted offers being the preferred type of repair initiator for all three groups in the visible condition. This aligns with the findings of Fusaroli et al., (2017), who also found that restricted offers are the most frequently used type of repair initiators in task-oriented conversations. However, when examining the hidden condition, the results suggest a different strategy for the children's groups, but not for the adult group. In the hidden condition, the two children's groups placed slightly more emphasis on restricted requests than in the visible condition, thereby slightly reducing the utilisation rate of restricted offers in the hidden condition as a compensatory measure. Once again, this demonstrates a lack of consistency among the children's groups because if restricted offers are considered more effective than restricted requests, restricted offers should be prioritized in the hidden condition, where maintaining common ground requires more effort. The children's groups thus appear to demonstrate a less optimised strategy for maintaining common ground through interactive repairs compared to the adult group. Similar to the rates of interactive repairs used, the two children's groups show no difference between them in terms of the chosen types of repair initiators.

2. How do conversational repair strategies vary across age groups in terms of efficiency?

We now examine repair efficiency, defined as the number of initiations needed to conclude a repair. Analysis uses median of the number of initiations per repair to avoid outlier influence. Lower medians are indicative of repairs needing fewer initiations to conclude, which we interpret as a marker of higher efficiency. Histograms comparing these medians across groups show higher efficiency in adults, especially in visible conditions (see Figure 8).

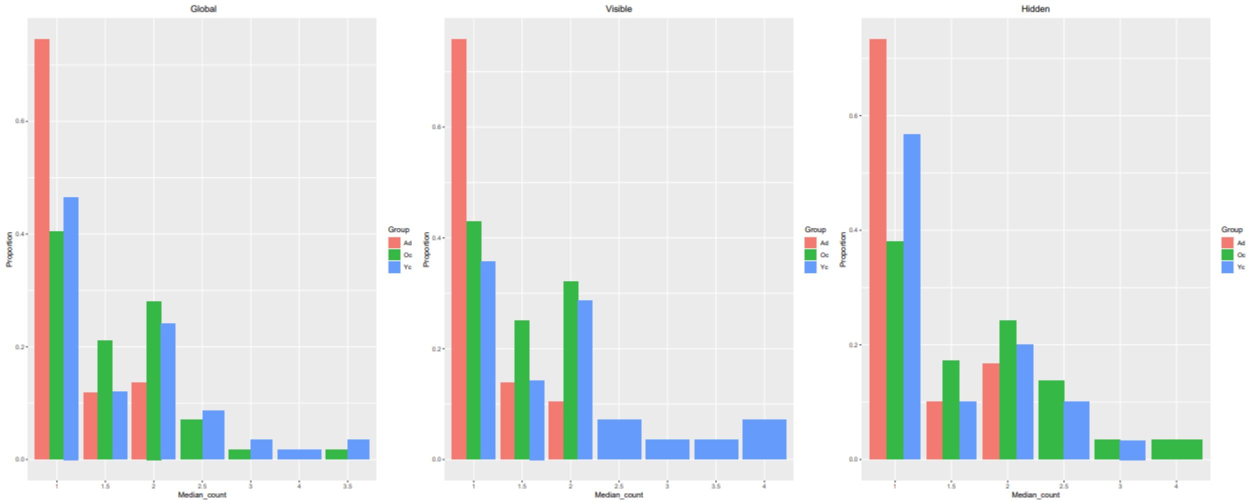

FIGURE 8 : Comparative histograms of median repair initiations across groups in different conditions (global, visible, and hidden). The red bars represent the adult group, the green bars the older children's group, and the blue bars the younger children's group. On the x-axis, we have the value of the medians, with lower medians indicative of sessions featuring effective repairs. The y-axis represents the proportion of sessions. Here, for example, we see that in the visible condition, about 70% of the adult sessions have a median of 1, meaning that in 70% of the adult sessions, repairs need only 1 initiation before being resolved.

When we focus on the visible condition, our model (see Figure 9) indicate that the session values for the adult group are significantly different from those of the younger children, with lower medians for the adult group, indicating repairs requiring fewer initiations before conclusion (Ad – Yc: estimate = -0.452; SE = 0.106; z.ratio = -4.261; $p < 0.0001$). However, when comparing adults to the older children group, there is no significant difference in the visible condition (Ad – Oc: estimate = -0.202; SE = 0.106; z.ratio = -1.905; $p = 0.0568$). Finally, the two children's groups are significantly different, with the older children's group having significantly lower medians than the younger children's group, suggesting more efficient repairs by the older children in the visible condition (Oc – Yc: estimate = -0.250; SE = 0.107; z.ratio = -2.340; $p = 0.0193$).

When we look at the hidden condition, the values are significantly different between the adult group and the older children, whereas there is no significant difference between the younger children's group and the adults. Within this condition, the values between the two children's groups are not significantly different. Then, the only group showing different values in the hidden condition compared to the visible condition is the younger children's group (Yc: estimate = -0.22755; SE = 0.08934; t = -2.547; p = 0.01086), (Oc: estimate = 0.16101; SE = 0.08910; t = 1.807; p = 0.07075), (Ad: estimate = 0.03589; SE = 0.08762; t = 0.410; p = 0.6821). Finally, when comparing the impact of the condition between the different groups, we find that the younger children's group experiences a significantly different impact from the other two groups (Yc – Ad: estimate = 0.26351; SE = 0.12513; t = 2.106; p = 0.03521), (Yc – Oc: estimate = 0.38851; SE = 0.12616; t = 3.079; p = 0.00207), whereas between the older children's group and the adults, the condition does not seem to have a significantly different impact (Ad – Oc: estimate = 0.12519; SE = 0.12496; t = 1.002; p = 0.3164). The median values for the younger children's group appear to be lower in the hidden condition than in the visible condition, while for the older children's and adults' groups, the values do not change significantly between the two conditions. Thus, the younger children's group employs more efficient repairs in the hidden condition than in the visible condition. In the hidden condition, the values are significantly different between the adult group and the older children group, whereas they are not significantly different between the younger children group and the adult group. In this condition, the values between the two groups of children are not significantly different.

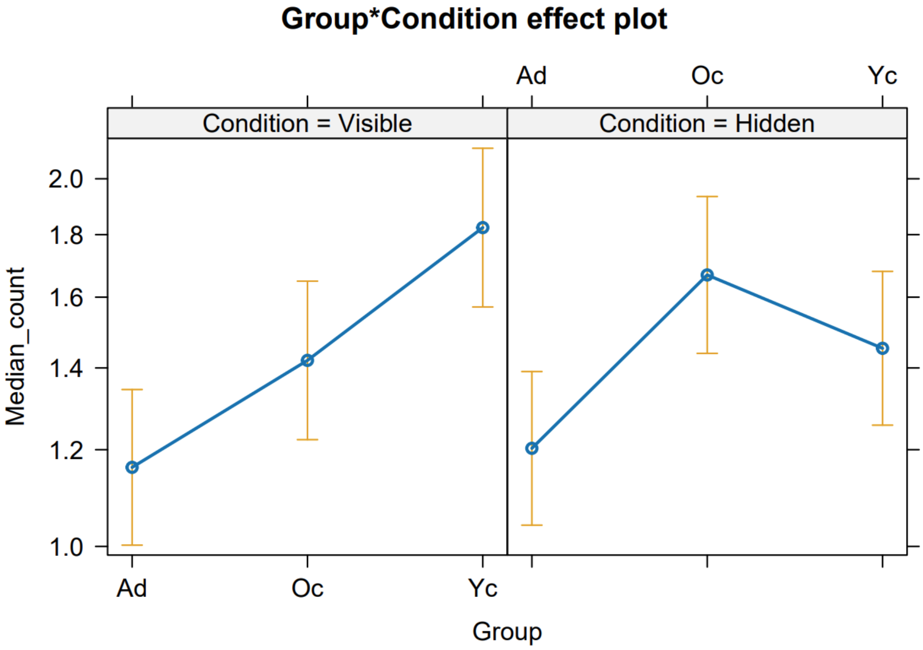

FIGURE 9 : GRAPH SHOWING THE AVERAGE OF THE MEDIAN SESSION VALUES FOR EACH GROUP AND FOR EACH CONDITION. A LOW MEDIAN VALUE INDICATES A GROUP WHERE REPAIRS TEND TO REQUIRE FEW INITIATIONS BEFORE CONCLUDING, WHILE HIGH VALUES OF THIS MEDIAN INDICATE A GROUP WHERE REPAIRS TEND TO REQUIRE MANY INITIATIONS BEFORE CONCLUDING. IN THE VISIBLE CONDITION, FOR EXAMPLE, WE CAN SEE VALUES OF THIS MEDIAN INCREASING WITH THE AGE OF THE GROUP, SUGGESTING LESS EFFICIENT REPAIRS BY THE YOUNGER GROUPS.

Interpretation of the results

We will now analyse the results representing the efficiency of concluding repairs within the different groups. Focusing on the visible condition, it is observed that the younger children's group is distinct from the other two groups. Indeed, both the adults and the older children display a similar efficiency in repairs in the visible condition, characterized by a low number of repair initiations needed before resolving a misunderstanding. The values for the younger children's group are significantly different from the other two, requiring a greater number of repair initiations to resolve misunderstandings. Therefore, we witness a shift in the repair usage strategy between the two children's groups, despite their close age range. This could suggest several interpretations; the first being that the difference in vocabulary level between the two age groups is substantial enough to account for this difference in repair strategies. The younger children may have a more limited vocabulary, increasing the difficulty of resolving misunderstandings due to an inability to find the right words to explain or correct an error. Another possible interpretation is that a cognitive capacity shift between the ages of 4 and 7 could underlie this difference. Given that cognitive development is significant within this age range, it may impact the ability to employ repairs effectively. A cognitive shift occurring within this age range could impact the cooperative abilities. Since resolving misunderstandings is the result of cooperation between two participants through interactive repairs, it's possible that the cooperative capacities of the younger children's group are significantly different from those of the older children. This difference could therefore be manifested through the observed disparity in the ability to resolve misunderstandings via interactive repairs. The older children, on the other hand, show the ability to perform repairs as efficiently as the adult group which suggests that, by the age of 7, children already possess the cognitive abilities necessary to carry out repairs as effectively as adults.

However, when examining the hidden condition, the adults' repair efficiency seems to be closer to that of the younger children than to the older children. Therefore, there is a larger gap in the efficiency of concluding repairs in the hidden condition than in the visible condition between adults and older children, whereas conversely, this gap is larger in the visible condition than in the hidden condition between adults and younger children. Nevertheless, despite a slight widening gap between the older children and adults, these two groups do not show a significant difference in repair efficiency depending on the condition. Meanwhile, the younger children's group demonstrates significantly higher repair efficiency in the hidden condition compared to the visible condition. This could be interpreted as the younger children's group exhibiting less repair efficiency in the visible condition, making it more apparent for this group to show improvement in the hidden condition compared to the visible condition. The other two groups, on the other hand, already exhibited very high efficiency rates (1 being the optimal rate with each repair requiring only one initiation before conclusion), and it was thus challenging for them to further increase this efficiency in the hidden condition. However, these results indicate that participants in the younger children's group already possess the ability to understand that more effort is required to coordinate in the hidden condition. Indeed, this increased effort can be observed into more effective repairs in the hidden condition than in the visible condition. Despite the fact that the baseline efficiency of interactive repairs is lower among the younger children, participants in this group still seem to understand that a greater investment is necessary to coordinate in the hidden condition. We can hypothesize that this increase in effort is not necessarily evident in the adult and older children's group since their repairs already showed high levels of efficiency in the visible condition, which makes increasing efficiency more complicated.

3. How does the role of repetitions in repairs vary across age groups?

We will now examine the role of repetitions within interactive repairs. When observing the rate of repetition across each type of repair (see Figure 10), it is found that Open Requests (OR) significantly exhibit fewer repetitions than both Restricted Requests (RR) and Restricted Offers (RO) (OR – RO: estimate = -3.905; SE = 1.020; z.ratio = -3.830; p = 0.0004)(OR – RR: estimate = -3.752; SE = 1.025; z.ratio = -3.659; p = 0.0007). On the other hand, RR and RO have similar rates of repetition (RO – RR: estimate = 0.153; SE = 0.154; z.ratio = 0.995; p = 0.320).

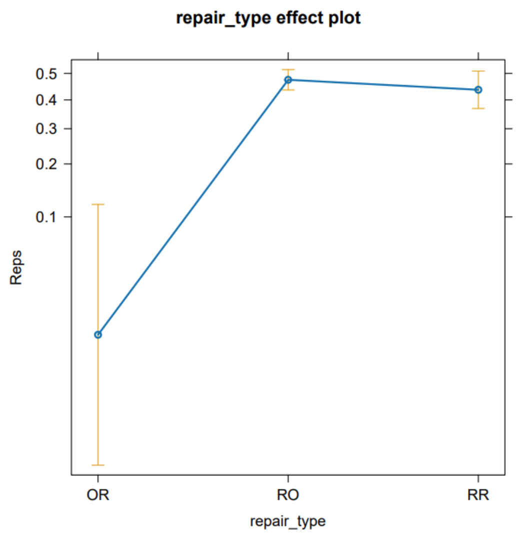

FIGURE 10 : IN THIS GRAPH, ON THE X-AXIS, WE HAVE THE DIFFERENT TYPES OF REPAIR INITIATIONS EMPLOYED (OR = OPEN REQUEST, RR = RESTRICTED REQUEST, RO = RESTRICTED OFFER), AND ON THE Y-AXIS, WE HAVE THE RATE OF REPETITION PRESENT IN EACH OF THESE DIFFERENT TYPES OF REPAIR. WE CAN OBSERVE THE RATE OF REPETITIONS WITHIN EACH TYPE OF REPAIR UTILISED. IT IS EVIDENT THAT REPETITIONS ARE SIGNIFICANTLY MORE PREVALENT WITHIN RR AND RO COMPARED TO OR. BOTH RR AND RO EXHIBIT SIMILAR RATES OF REPETITIONS.

When we then look at the repetition rates employed by each group (see Figure 11), in the visible condition, the repetition rates are similar among all three groups (Ad – Oc: estimate = 0.397; SE = 0.274; z.ratio = 1.452; p = 0.1466)(Ad – Yc: estimate = -0.037; SE = 0.244; z.ratio = -0.152; p = 0.8794)(Oc – Yc: estimate = -0.434; SE = 0.247; z.ratio = -1.758; p = 0.0788). In the hidden condition, repetition rates are consistent across the groups, with the exception of the adult group and the older children's group, where the adults exhibit a higher number of repetitions (Ad – Oc: estimate = 0.559; SE = 0.222; z.ratio = 2.522; p = 0.0117)(Ad – Yc: estimate = -0.397; SE = 0.214; z.ratio = 1.859; p = 0.0630)(Oc – Yc: estimate = -0.161; SE = 0.223; z.ratio = -0.724; p = 0.4691).

When comparing the repetition rate between the two conditions (see Figure 11), each group employs significantly more repetitions in the hidden condition than in the visible condition (Ad: visible – hidden: estimate = -1.237; SE = 0.218; z.ratio = -5.680; p < 0.0001)(Oc: visible – hidden: estimate = -1.075; SE = 0.233; z.ratio = -4.624; p < 0.0001)(Yc: visible – hidden:

estimate = -0.802; SE = 0.188; z.ratio = -4.267; p < 0.0001). Moreover, the condition does not seem to have a significantly different impact depending on the group (Ad – Oc: estimate = -0.16164; SE = 0.31726; z = -0.509; p = 0.610414)(Ad – Yc: estimate = -0.43448; SE = 0.28578; z = -1.520; p = 0.128432)(Oc – Yc: estimate = -0.2728; SE = 0.2939; z = -0.928; p = 0.353380).

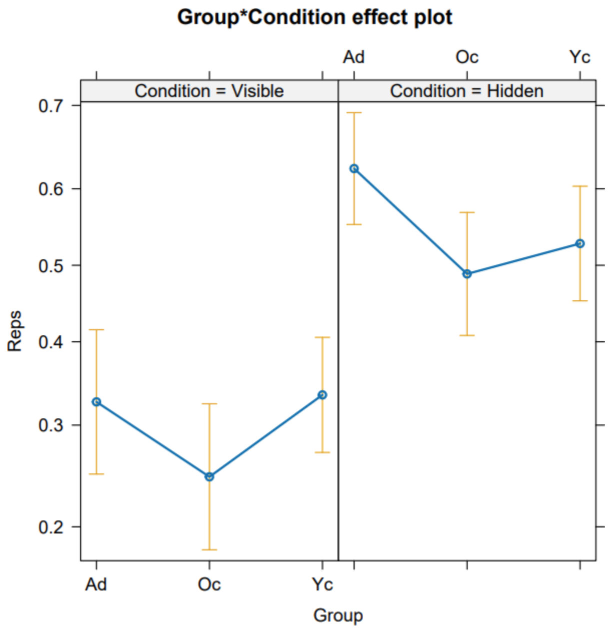

Figure 11 : In this graph, the x-axis represents the two conditions as well as the different groups. The y-axis, meanwhile, displays the rates of repetitions used during interactive repairs. A value of 0.1 describing, for example, a single occurrence of repetition every 10 interactive repairs. It is clearly observed that there is a higher rate in the hidden condition for each of the groups compared to the visible condition.

Interpretation of the results

We will now attempt to interpret the significance of repetitions within interactive repairs. Initially, when examining the relationship between repetitions and the type of repair initiation, it is observed that repetitions are significantly more prevalent within restricted initiation types compared to open requests. Indeed, one of the characteristics of restricted initiations is to repeat what was said to ensure it was understood correctly, which aligns with our findings. However, between restricted requests and restricted offers, no difference in repetition rates is noted, with similar rates of repetitions regardless of whether it involves a restricted request or a restricted offer.

When examining the visible condition, repetition rates are similar across all groups, with approximately 2 to 4 occurrences of repetition per 10 interactive repairs. Thus, the emphasis placed on repetitions within interactive repairs seems to be consistent regardless of the participants' ages. Every participant in the experiment appears to assign the same importance to the repetition of a misunderstanding in order to resolve it. When looking at the hidden condition, each group places greater importance on repetitions. Indeed, every group exhibits significantly more repetitions in the hidden condition compared to the visible condition. The various groups seem to similarly understand the importance of repeating our interlocutor's vocabulary for better mutual understanding and more effective resolution of misunderstandings. This indicates that from the age of 4, we already seem to grasp the significance of repetitions and know how to adapt this language capability based on its necessity. This is consistent with the understanding that the ability to repeat others' language is known to be crucial in language learning. Indeed, from a very young age, children are already capable of repeating words spoken to them in order to learn them better. The need to master this capability early in our development could be why, by the age of 4, we already possess abilities to handle repetitions within interactive repairs very similarly to adults, given that this ability to repeat words must have been mastered for other reasons at an earlier age. No difference is observed in the rates of repetitions used between the two children's groups, thus supporting the hypothesis that by the age of 4, the ability to master the use of repetitions is already well-developed. The switch to mastering this ability occuring before the age of 4, and therefore, no difference is observed beyond this age. These findings may indicate that all groups share an understanding of the increased necessity to maintain common ground in the hidden condition. Which is observed through a greater repetition of the terms used in each group. Indeed, repetitions play a crucial role in maintaining common ground, as they not only acknowledge and ratify another's contribution but also signal the incorporation of specific information into common ground (Clark & Bernicot, 2008).

However, despite each group displaying similar repetition strategies with an increase in the hidden condition, the repetition rate in the hidden condition is significantly higher among adults than in the older children group. This could indicate that, despite very similar strategies among the groups, the ability to employ repetitions within interactive repairs may still be enhanced from the age of 7 to adulthood. Adults seem to rely more on repetition as a compensatory mechanism in challenging communication scenarios. This reliance might not be as pronounced in children, possibly due to their different approach to problem-solving or communication. Children might use other strategies which are not captured solely by measuring repetition rates. The overall results thus suggest that the major shift in this capability occurs before the age of 4, however, post-4 years, this ability can still undergo slight improvements before reaching the exact level observed in adults.

4. How do different groups vary in their associative use of visual cues and repair initiations?

We will now explore the association between repairs and modalities other than language, such as gestures. Specifically, we will examine instances where repair initiations required visual feedback from the other partner, for example, when the builder asked the director if they had the correct piece by pointing at it or showing it directly in their hand. When focusing on the visible condition (see Figures 12 & 13), the adult group tends to associate significantly fewer visual feedbacks compared to the other groups (Ad – Oc: estimate =

1.5893130; SE = 0.3705275; z = 4.289; p = 1.79e-05) (Ad – Yc: estimate = 1.1535989; SE = 0.3349249; z = 3.444; p = 0.000572). Between the two children's groups, there is no significant difference observed (Oc – Yc: estimate = -0.4357; SE = 0.3539; z = -1.231; p = 0.218).

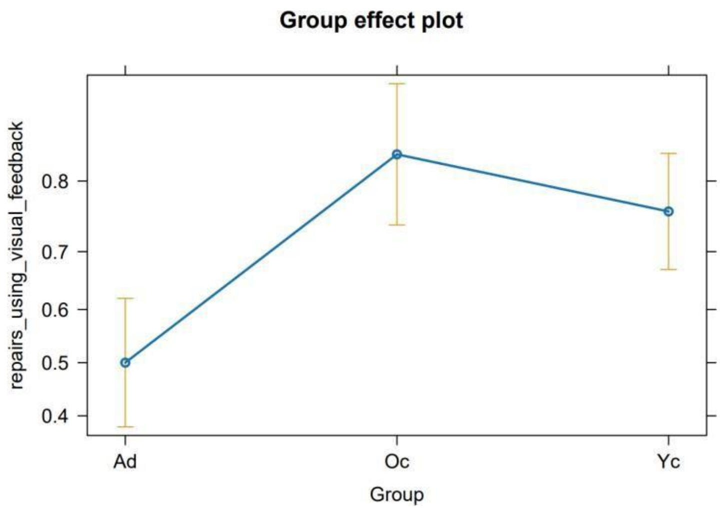

FIGURE 12 : GRAPH DEMONSTRATING THE DIFFERENT GROUPS ON THE X-AXIS AND THE RATE OF REPAIR INITIATIONS INCORPORATING GESTURAL MODALITIES SUCH AS POINTING ON THE Y-AXIS. IT IS OBSERVED THAT CHILDREN TEND TO USE GESTURES AND VISUAL FEEDBACKS MORE THAN ADULTS.

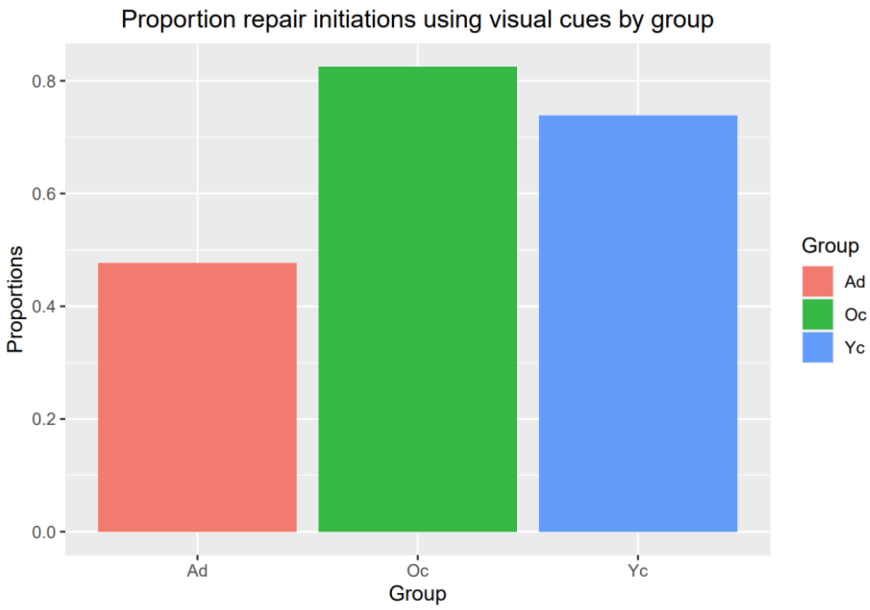

FIGURE 13 : HISTOGRAM SHOWING THE PROPORTION OF REPAIR INITIATIONS ASSOCIATED WITH GESTURES OR VISUAL FEEDBACKS FOR EACH OF THE 3 GROUPS. LESS THAN 50% OF THE INITIATIONS AMONG ADULTS INVOLVE THIS ASSOCIATION, WHILE WITHIN THE CHILDREN'S GROUPS, 70 TO 80% OF REPAIR INITIATIONS ARE ASSOCIATED WITH GESTURES OR VISUAL FEEDBACKS.

When we turn our attention to the hidden condition, despite gestures being ineffective since the two participants cannot see each other, some repair initiations were still associated with gestures and visual feedbacks. Specifically, 7 instances were noted for the older children's group, 13 for the younger children's group, and 0 for the adult group.

Interpretation of the results

We will now focus on the simultaneous use of words and gestures in the initiation of repairs. Our results indicate a clear preference among the children's groups for combining gestures and words during the initiation of a repair. Specifically, adults tended to make this association in about one out of every two initiations, whereas children demonstrated a real preference for combining these two modalities, with almost every initiation involving an association. These results demonstrate a distinct inclination among children to integrate gestures with verbal communication to improve understanding. The data suggests several possible interpretations. Primarily, the necessity for children to employ gestures alongside words could stem from their relatively limited vocabulary, which requires compensatory measures to overcome lexical deficiencies and ensure their messages are conveyed effectively. Furthermore, considering that children initially learn to use gestures before words (Bates, 1976) and that these gestures play a significant role in their language acquisition (Clough & Duff, 2020), the combination of gestures and words may remain pronounced up to the age of 7. This could explain the emphasis on gestures and visual feedback within interactive repairs among children's groups.

Our histogram results seem to show a heightened preference for this association within the older children's group; however, the difference in association between the two children's groups is not significant. The absence of difference between the two children's groups may suggest that the ability to rely primarily on words rather than gestures emerges after the age of 7. Prior to this, the lexical capabilities available to children between the ages of 4 and 7 constrain them to combine gestures and words to enhance understanding, at least in the context of employing repairs within task-oriented conversations.

When examining the association of gestures and words in repair initiations under hidden conditions, despite the fact that this association is redundant as the opposite participant can no longer see the gestures, the children still show some occurrences of associations—7 in the older children's group and 13 in the younger children's group (which still corresponds to a relatively low occurrence rate compared to the total number of repair initiations in hidden conditions: 0.03 for older children and 0.05 for younger children). These occurrences, although rare, and especially their comparison with the adult group, which exhibited none, could suggest that the theory of mind is not yet fully developed in some individuals of the children groups (Wellman, 2018). Indeed, the ability to understand that individuals we interact with can have different perspectives from our own, and the capability to grasp which information is actually accessible to others, are tied to our theory of mind. However, this cognitive ability may not be fully developed by the age of 7, or at least some children may exhibit a delay in its development. This could explain the occurrences of gesture-word combinations during the hidden condition for certain participants in the children's groups.

However, the persistent use of gestures in repair initiations by children, even in hidden conditions, might not solely indicate an underdeveloped theory of mind. It could also reflect a habitual or instinctive use of gestures as part of their communication repertoire. Children, in the early stages of linguistic and communicative development, might rely on gestures as a natural part of expressing themselves, regardless of whether their communication partner can see them. This tendency might be less pronounced in adults, who have more experience relying solely on verbal communication, especially in contexts where visual cues are unavailable. Therefore, the children's use of gestures in hidden conditions might also be seen as a reflection of their developmental stage and holistic approach to communication, integrating both verbal and non-verbal elements, rather than a clear indication of an incomplete theory of mind. This also illustrates the fact that the need to be understood precedes the need to optimize language strategies. Indeed, if we accept that adults possess more optimized linguistic capabilities due to their experience and more advanced cognitive abilities, then children, despite their evident capacity to align lexically with their partners and to carry out repairs effectively, might prefer to add gestures to their repair initiations. This combination of gestures during explanations and attempts to correct misunderstandings probably allows them to resolve language errors more quickly and efficiently. Rather than strictly adhering to the most optimized strategy, defined as the one used by adults, children may prioritize enhancing their chances of being understood first and then gradually improve their linguistic capabilities as they develop.

Discussion

By investigating the development of repair strategies, this study aimed to enhance our understanding of how coordination strategies and the maintenance of common ground in joint actions evolve over time. Considering that interactive repairs embody behavioural characteristics which enhance cooperation and facilitate the preservation of common ground (Heesen et al., 2022), they serve as a highly effective research instrument for investigating how common ground is sustained throughout cooperative activities. We therefore hypothesized that a shift in cognitive abilities, enabling enhanced coordination particularly through the preservation of common ground, could be reflected in varied repair strategies across different age groups.

The absence of differences observed between the 2 children age groups, in terms of repair frequency, choice of repair initiator, rates of repetitions, and use of visual cues, can probably be explained by similar cognitive development stages compared to adults. Indeed, significant differences are primarily observed between the adult and children groups. The differences between the children are more subtle, and the significance is likely more challenging to discern within the various aspects of language. Studies with a larger dataset would probably be more suitable if one wished to focus specifically on the differences between the children's groups.

The majority of our results seem to indicate a difference in the adaptation of repairs among the different groups, with children having more difficulty adapting their repair strategies according to the task's difficulty. This seems to be primarily because children habitually use significantly more visual cues in their repair strategies. As a result, in the hidden condition, when their ability to include visual cues in repair initiations is limited by the curtain placed between the two participants, the children's repair strategies are more adversely affected than those of the adults. The hidden condition appears to pose a much greater challenge for the children's groups than for the adult group, as evidenced by the more drastic decrease in success rates among the children's groups compared to the adult group (see appendix F). This aligns with the understanding that lexical capacity is lower in children, making visual cues a more viable option for comprehension, particularly in the presence of lexical gaps or a limited vocabulary, and especially to illustrate certain shapes and colours of pieces. However, the complexity of shapes and colours varied between the children's groups and the adult group. Thus, it can be inferred that adults are less likely to use visual instructions than children, despite increased difficulty in being understood. Adults might tend to prioritize verbal repair resolution over associations of verbal and gestural indications.

These differences in adaptability are largely attributable to the fact that the change in condition represents a greater increase in difficulty for the children's groups than for the adult group. This is particularly evident in the success rates of the models, for which it is observed that the difference in success between the two conditions is significantly lower in the hidden condition than in the visible condition, exclusively for the two children's groups. The distinct strategies employed by the groups in their use of interactive repairs probably play a crucial role in this difference. If the success rate is partly related to the strategies of using interactive repairs, then the varied application of repairs between adults and children could be one factor contributing to this difference in success rates. Naturally, while interactive repair is crucial in resolving tasks of varying complexity, such a task also relies on other cognitive abilities, including spatial representation, inter-individual alignment, coordination, or theory of mind.

Furthermore, our results have demonstrated different strategies in the use of repairs between adult and children groups. Specifically, children used fewer repairs per number of words in hidden condition compared to visible condition, which was not observed in adults. This is likely primarily due to the fact that children have a greater tendency to combine gestures and words in their repair initiations. Indeed, if we consider that this combination tends to reduce the number of words used – for example, by saying 'this piece?' instead of 'the dark green piece?' or 'like this?' instead of 'on the red piece that's right at the top?' – then this explains the decrease in the number of repairs per number of words in children. Since they could no longer combine gestures with their repair initiations in the hidden condition, they were forced to carry out repairs using only words which decreases the number of repair per words and aligns more closely with the repair strategy employed by adults.

These results indicate that despite significant development in cognitive abilities among children between the ages of 4 and 7, no cognitive difference reflected by a variance in repair strategies is observed within the two groups of children. Moreover, the major differences between the two groups of children and the adult group suggest that after the age of 7, children must undergo certain cognitive improvements, social experiences, or enhancements in lexical and coordination abilities before demonstrating repair strategies similar to those observed in adults. However, our findings still identified a slight difference in the repair strategies between the two groups of children. Specifically, when measuring the effectiveness in resolving interactive repairs, older children demonstrated more efficient repairs in the visible condition, requiring fewer initiations before resolution (results similar to those of adults). This could indicate that a cognitive shift may indeed occur between the ages of 4 and 7, particularly manifesting through an increased efficiency in concluding repairs. This ability to resolve misunderstandings more effectively among the older children's group can be interpreted as a higher capacity for coordinating with a partner to solve a problem together.

Our findings, especially the observation of multiple differences between adults and children, indicate that our abilities to coordinate during joint actions, maintain common ground, and adapt these abilities are still underdeveloped between the ages of 4 and 7. This reflects the substantial gap in coordination capabilities between adults and children, highlighting the significant developmental journey that occurs beyond the age of 7 in terms of refining cognitive and cooperative skills essential for effective joint actions and problem-solving. However, a slight cognitive shift has been observed between the two children groups, particularly reflected through the differences in repair efficiency. Given that interactive repairs rely significantly on cognitive abilities such as theory of mind, we can infer that, although these capabilities are still quite immature between the ages of 4 and 7, they nevertheless experience a slight evolution during this age range. Given their critical role in sustaining common ground, repairs can therefore represent a major instrument that reflects diverse coordination skills and capacities to calibrate our understandings (Dingemanse & Enfield, 2023).

These findings have significant implications for our understanding of language development and the role of multimodal communication strategies. The reliance of children on visual cues for repair strategies suggests the need for educational approaches that integrate multimodal communication, especially for younger learners. Language research has mainly focused on studying individual aspects of language, such as grammar, phonology, or syntax, in isolation. However, recent advancements point towards the need for a more integrated approach. The different processes of language are rarely considered together, limiting our view of possible interrelations. There is a real importance of simultaneously examining multiple mechanisms and exploring various social activities to fully comprehend their functions and interrelationships in language (Fusaroli et al., 2017).

Multimodal studies reveal that language is a rich, interactive process, deeply embedded in social contexts and which involves not just words but also gestures, facial expressions, tone, and context, all working together to create meaning. This complexity of language requires an understanding of how these various elements interact and influence each other. Instead of studying each modality in isolation, future studies should focus on how these different elements interact and contribute collectively to communication. There is a real need to recognize the interconnectedness of these modalities in real-world interactions and seek to study them in a more holistic manner. The future of language research, therefore, lies in embracing this complexity and investigating language as a dynamic, integrated system, bridging the gap between qualitative and quantitative research methods, and exploring the interplay of various linguistic modalities (Alviar et al., 2023; Trujillo et al., 2023).

Furthermore, exploring how different educational interventions can support the development of more complex verbal communication skills in children would also be valuable. Investigating the differences in repair strategies across a broader age range and in various cultural contexts could provide a more comprehensive understanding of language acquisition. Finally, studying the impact of such multimodal communication strategies on children with developmental delays or communication disorders could offer insights into effective therapeutic approaches.

Limitations

The rooms used for the children were more susceptible to ambient noise, leading to more background noise in the children's groups than in the adults'. Sound also seemed to propagate less effectively in the rooms used for the children's groups, with a slight echo present. These factors could have potentially influenced not only the overall number of repairs in the children's group but also the number of initiations required to conclude a repair. The background noise and poor room acoustics could have led to an increased need for more frequent repairs and a higher number of initiations for effective repair resolution, thereby potentially affecting mutual understanding between participants in the children's groups differently than in the adult group.

The success of the models was counted only when the model was exactly the same as the requested one. However, there were instances where the models were very similar, with only a minor difference in perspective, such as mirror-image models, and other times, the models were completely different, with very distinct pieces and some pieces entirely missing. A more nuanced assessment of model success could have considered the degree of success by taking into account the number of pieces misplaced or the type of error (placement, incorrect colour, mirror effect, etc.). This approach would have been more representative of the true success rate of the models, rather than a simple binary count of success or failure.

Given that the adult and children groups represent different cognitive levels, we had to present them with construction models adapted to their cognitive abilities. However, it is very challenging to precisely estimate the exact difficulty level of a task in relation to cognitive capabilities. Therefore, we cannot ensure that the task levels were equivalent for each group and that they corresponded to the relative cognitive abilities of each group.

In some cases, it wasn't apparent to the pair of adults participants whether they were permitted to point to the LEGO pieces with their fingers and present them to their interlocutor, potentially impacting the number of repair initiations coupled with visual feedback. However, some participants hesitated and occasionally asked for permission to point to the pieces, while others self-restricted from doing so. Conducting a future experiment with more explicit instructions might yield better results and confirm that all participants understand the allowance of gestures in repair initiations. However, it's important to note that our experiment only considered the construction of models from the second one onwards and by this stage, participants seemed to have a clear understanding of the experiment's rules.

Conclusion

Our findings underscore the importance of studying repair strategies within the context of coordinating joint actions. Indeed, these play a crucial role in our ability to coordinate, particularly by facilitating the maintenance of common ground among individuals attempting to cooperate in joint activities. Differences in our use of interactive repair strategies according to age could thus reflect potential differences in our abilities to coordinate during joint activities throughout our development. Given the significant cognitive development that children undergo between the ages of 4 and 7, we anticipated that these changes could be reflected by different strategies in the use of repairs between the two groups of children, with the older children demonstrating repair strategies more similar to adults than the younger children.

However, the results of our experiment primarily demonstrate a major difference between children and adults in their capacity to coordinate through the use of interactive repairs. This was observed through better optimization of repair use within the adult group, notably through higher rates of repair frequency, more effective choices of repair initiators, more efficient interactive repairs, and better adaptation of repairs when visibility between participants was obstructed. These findings indicate that by the age of 7, children still need to undergo certain cognitive changes and improve their language capabilities and maintenance of common ground before they can reach coordination abilities similar to those observed in adults.

While our results might lead one to believe that no cognitive switch occurs between our two groups of children observable through different repair strategies, a difference suggesting a cognitive switch in coordination abilities was observed in the efficiency of repairs. Specifically, in visible conditions, the older children approached the capabilities of the adults more closely than those of the younger children. This group required fewer repair initiations before resolving a misunderstanding, comparable to the adult group. In contrast, the younger children showed greater difficulty in resolving misunderstandings compared to the other two groups.

The nuanced differences in repair efficiency and strategies across age groups indicate a gradual, rather than abrupt, cognitive transition in the development of coordination capabilities. This gradual progression underscores the complexity of cognitive development, suggesting that while younger children may encounter more challenges with misunderstandings, their evolution toward more adult-like coordination and communication strategies is continuous and nuanced. Furthermore, this development does not halt at the age of 7 but continues to evolve, indicating that the refinement of these skills extends beyond early childhood. The age-related improvement in repair efficiency not only points to a refinement in linguistic skills but also suggests an enhancement in social cognition and problem-solving abilities between 4 and 7 years old children. These abilities are crucial for navigating the complexities of social interactions and joint activities, underscoring the interplay between cognitive development and social coordination. This insight into the developmental trajectory offers a deeper understanding of how children learn to navigate social interactions more effectively, refining their use of language as a tool for cooperation and mutual understanding.

Moreover, our findings demonstrate the importance of incorporating interactive repairs into the study of coordinating joint actions. Indeed, this ability can serve as a tool to better understand certain cognitive differences between different age groups.

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Supporting Information

Appendix A. Recruitment Flyer.

Appendix B. Lego models for children's groups

Appendix C. Lego models for the adult group

Appendix D. Coding-scheme used for transcription[1]

Appendix E. Coding-scheme used for repair analysis

Appendix F. R Markdown file sowing the results

Appendix G. Dataset underlying the findings (Annexe)

Statement: During the preparation of this work, I used Chat GPT to help me reformulate my ideas from French into correct English sentences. After using this tool/service, I reviewed and edited the content as needed and take full responsibility for the content.

[1] Coding-scheme from (Morozova, N., Stoll, S., & Bangerter, A. (2025). Convergent evolution of project markers: Universal strategies of joint action coordination [Supplemental material] [Manuscript in preparation]. Department of Comparative Language Science, University of Zurich, Zurich, Switzerland.)

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Appendix A

RECRUTEMENT ÉTUDE
GAGNEZ 10.- EN JOUANT AUX LEGO®
PARTICIPEZ À NOTRE ÉTUDE SUR LA COOPÉRATION ET LA COORDINATION. INSCRIVEZ-VOUS À L'AIDE DU QR CODE CI-DESSOUS.
CONDITIONS :
- AVOIR ENTRE 18 ET 30 ANS
- LANGUE NATALE : FRANÇAIS
INSTITUT DE BIOLOGIE
Contact : luca.romanazzi@unine.ch
unine
Université de Neuchâtel

Appendix B

Children models

Control Model

Model 1

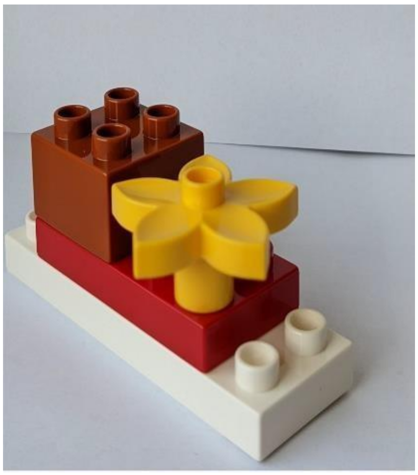
Model 2

Model 3

Model 4

Model 5

Model 6



Model 7

Model 8

Model 9

Model 10

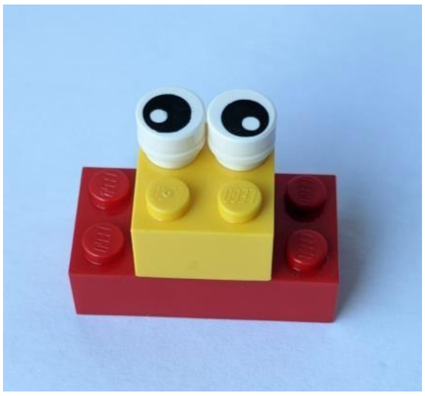
Distracting pieces

The data for this experiment was exclusively collected from the construction of models 2, 3, 7, and 8

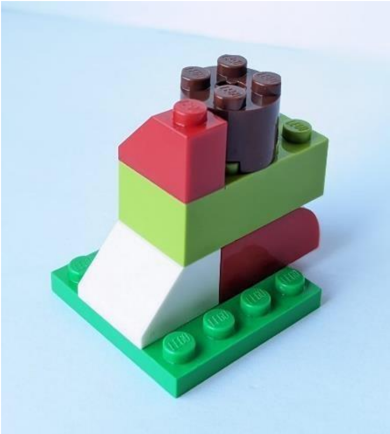
Appendix C

Adult models

Control Model

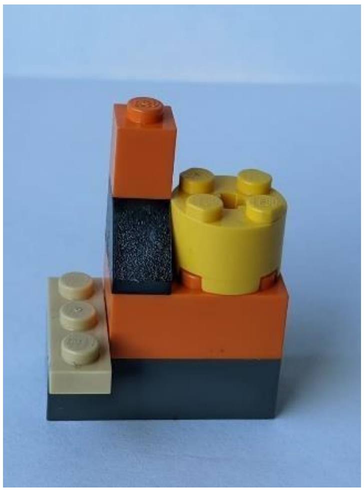


Model 1



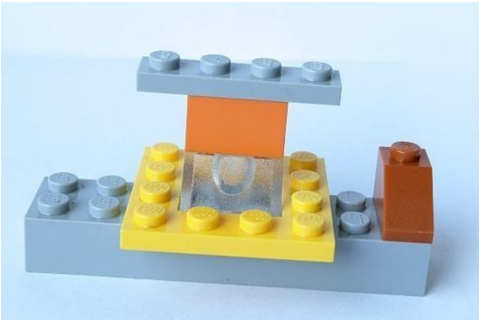
Model 2

Model 3



Model 4

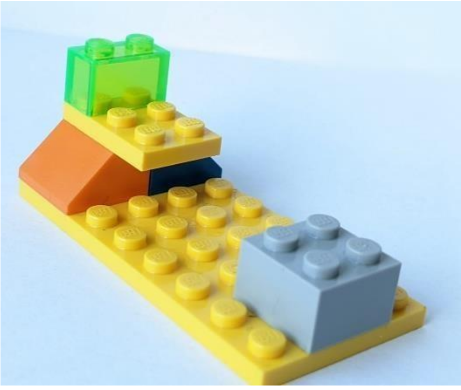
Model 5



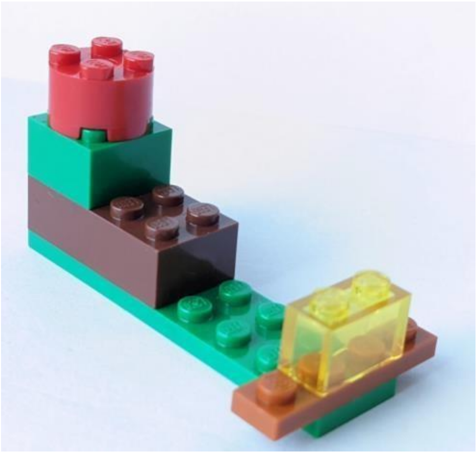
Model 6

Model 7

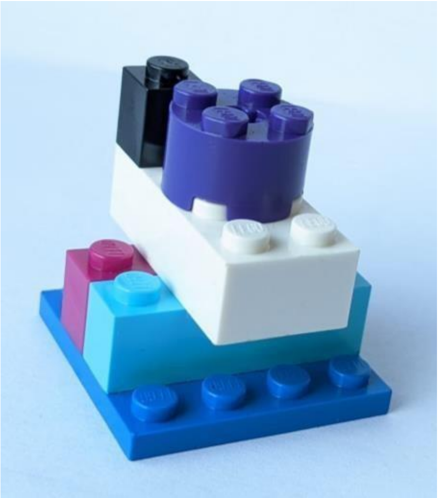
Model 8



Model 9



Model 10



Distracting pieces

The data for this experiment was exclusively collected from the construction of models 2, 3, 7, and 8.

Appendix D

BACKtalk manual

Transcribing conventions

All transcriptions should be written only in the corresponding **text@d_ABC** and **text@b_ABC** tiers. Tier **text@d_ABC** is for director's speech and **text@b_ABC** is for builder's speech. Try not to leave any transcription segments empty. The text tiers contain a wide but accurate transcription of what a speaker actually said. You always transcribe the speech exactly the way it is pronounced, including the following cases:

- fast/slurred speech
- colloquial speech
- halting/broken speech: *This is a black six-by… Um… Six-by-two.*
- slips of the tongue, stuttering: *Can you show me the mo-model?*
- intended repetitions: *Yes, there there there there!*
- self-corrections: *That's a really easy, er, difficult model.*
- false starts: *Now you take a ye- uh transparent yellow block.*

If speakers mispronounce a word or make a grammatical mistake, you should not correct their errors in the transcripts. Instead, indicate it in the **com@** tier.

	text@d_ABC	com@d_ABC
145	Avec le, avec ce que t'as djà construit. Et pis t'en mets deux derrière, c'est là que tu les mets	Pronunciation error: should be "déjà" instead of "djà". Pronunciation error: should be "puis" instead of "pis"

Punctuation rules

Punctuation: rules are as in French. It is fine to use regular punctuation marks. However, avoid using brackets *( ) [ ] { }* in the **text@** tiers.

Problematic word types

There are some cases where pronunciations can be mapped to spellings in different ways:

- **Names** or **nicknames** should be uppercased as in French.
- **Abbreviations**, **acronyms**, **numbers** and **letters**. The rule here is to spell out everything the way it is pronounced, e.g. *Professor* (not *Prof.*) and *five* (not *5*).
- **Loanwords** or **foreign speech**. Participants might switch to other languages or occasionally use foreign words, e.g. Swiss German or Italian. You should not translate those words or sentences into French in the **text@** tiers. Instead, you should transcribe them in French orthography and indicate the use of a foreign word in the **com@** tier.

Unclear speech

Occasionally, you might encounter unclearly pronounced words or phrases. To indicate an unclear speech segment, use **xxx** instead. In case of doubt, it is better to use **xxx** than to make a guess. If you can hear the exact number of unclear words (for instance, two words), use the **com@** tier to leave a remark with each single **x** representing an unclear word.

If you hear that there are exactly three words which meaning is unclear to you, include x for each unclear word:

text@d_ABC Oh, moi j'en ai xxx

com@d_ABC Oh, moi j'en ai x x x

	text@d_ABC	com@d_ABC
282	Oh c'est quoi ça?	
283	Espèce de...	Not sure of this transcription
284	Oh, moi j'en ai xxx	x x x

Non-verbal communicative signals

Non-verbal communicative signals with a clear communicative intent such as laughter, whistles, signs, groans, cries, screams, etc. should be segmented but not transcribed in the **text@** tiers. Instead, leave the transcription empty and indicate that a participant is laughing or screaming in the **com@** tier. If the participant is laughing along pronouncing something, transcribe the speech and indicate laughter in the **com@** tier.

	text@b_ABC	com@b_ABC
227		Laughter

	text@b_ABC	com@b_ABC
193	Ouais eh	Laughter

Reaction tokens

Agreement tokens and other non-lexical reaction tokens are very important for this project. In a conversation, speakers and listeners have to continuously agree that speakers' words are understood. To minimise the time and effort of indicating this agreement, listeners signal the understanding with **verbal and non-verbal agreement tokens**. Verbal agreement tokens are predominantly short, non-lexical utterances produced by the listener to signal their understanding. Common agreement tokens in French are *OK, ouais, humhum, hum*, etc.

Other reaction tokens include non-lexical signals to express disagreement (*non*) or surprise (*oh, ah, ah bon*). Additionally, speakers often need time to remember a particular word or formulate the utterance. To indicate the hesitation, they use fillers such as *euh, mm, ben*.

It is essential that you pay close attention to everything that is said by participants and do not miss any non-lexical reaction tokens.

Non-comprehensive list of reaction token spellings currently used for the project

	English	French
Agreement tokens	okay, all right, yeah, yes, yep, right, mhm, uh-huh, uh-hum, mm-hm, mm	OK, voilà, ouais, oui, humhum, hum, ah, d'accord, ah oui
Disagreement tokens	uh-uh, nope, nah	non
Surprise tokens	huh, a-ha, oh	oh, ah, ah bon, ah oui
Fillers	um, uh, hm, mm, er, well	euh, mm, bon, ben

Comment tier

This section summarises the main functions of the **com@** tier, which should be used for any research-related comments, such as the following:

- to indicate when participants speak to the experimenter
- to explain any unusual content in the **text@** tiers, e.g. the use of foreign words, colloquial speech, non-standard dialect words or constructions
- to indicate grammatical or pronunciation errors (e.g., *incorrect form = correct form)*
- to indicate the number of unclear words
- to explain unusual word choices, e.g. if it is clear that participants use a nickname instead of an actual name of their experiment partner
- if participants prolong a phoneme or a syllable. Usually we indicate the length of a phoneme in transcripts; however, we will use automatic translation software, and weird transcriptions might confuse the algorithm. Therefore, please note down any prolongations in the **com@** tiers, e.g.

text@b_ABC	Okay
com@b_ABC	‘A’ in okay is prolonged (okaaaaay)

Appendix E

Ways of repair – manual

“Conversational repair is the process people use to detect and resolve problems of speaking, hearing, and understanding. Through repair, participants in social interaction display how they establish and maintain communication and mutual understanding” (Albert & Ruiter, 2013). Once an problem in the communication is recognized, the correction can be initiated by either the speaker or the listener.

Other-initiated repairs (OIR) (https://doi.org/10.1515/opli-2016-0002):

In this case, the repair is initiated by the recipient of the trouble source. We will identify the trouble source, the initiation of the repair and the repair by adding T-1, T0 and T+1 in the respective lines of the column titled “OIR”.

Here are some examples:

Extract 19

	Column1	Column2	Column3	Column4
2	text@d_ABC	text@b_ABC	OIR	Type of OIR
215	Une elle est rose c- pâle et l'autre elle est bleu clair		T-1	
216	Et c'est des pièces épaisses			
217		épaisses euh t'as dit rose pâle?	T0	restricted offer
218	Ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

Extract 20

	Column1	Column2	Column3	Column4
2	text@d_ABC	text@b_ABC	OIR	Type of OIR
84	Euh on va mettre un ptit toit dessus donc ça c'est une pièce vert clair euh épaisse quat sur euh quat sur deux		T-1	
85		Attends vert clair quat sur deux?	T0	restricted offer
86	Ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

In extract 20, we start by identifying the initiation of the repair (T0) at line 85, which signals trouble in a previous turn. Then, we need to determine the T-1 and T+1, which are defined in relation to T0. The trouble source (T-1) often directly precedes T0. Lastly, following T0, T+1 will mark the conclusion of the repair process. Often, T+1 indicates a potential repair solution to T0.

However, in extract 21, which represents the continuation of extract 20, we can observe that the repair of this trouble source is not yet completed. Indeed, in line 91, the builder asks for additional information regarding what the director said in line 84. Since the trouble source remains the same, we introduce another T0 in line 91, and the resolution of the repair process will occur in line 97.

Extract 21

	Column1	Column2	Column3	Column4
2	**text@d_ABC**	**text@b_ABC**	**OIR**	**Type of OIR**
85		Attends vert clair quat sur deux?	T0	restricted offer
86	Ouais		T+1	
87	épaisse			
88	Est-ce que t'as ça?			
89		Ah ouais		
90	Et pis ça du coup tu peux la mettre...			
91		Mais vert clair du coup?	T0	restricted offer
92	Ouais vert clair			
93		Pce que j'ai une vert foncé		
94	Ah mais je sais pas si c'est euh...			
95		Euh		
96	Moi j'ai une vert, c'est vraiment un peu une, un vert euh...			
97	Un peu pomme un peu		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

Extract 22

	Column1	Column2	Column3	Column4
2	**text@d_ABC**	**text@b_ABC**	**OIR**	**Type of OIR**
99	Et du coup celle-là faut la mettre par-dessus les deux rampes		T-1	
100	Euh et elle va dépasser du côté de la rampe rouge			
101		Du coup elle d- ouais	T0	restricted request
102	Donc si tu veux elle va, elle va, elle va couvrir...			
103		Fin les quatre et, les quatre euh ptits picots i seront pris	T0	restricted offer
104	Ouais		T+1	
105	Euh			
106		Non les six p-...	T0	
107	Les six ptits picots sont pris		T+1	
108		Pi-...		
109		Picots sont pris, y en aura jus deux qui, ouais ok	T0	
110	Ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

Here in extract 22, the trouble source starts at line 99, and then the director and the builder attempt to repair the misunderstanding together. In line 101, we can observe that T0 doesn't always precede a T+1.

Extract 23

	Column1	Column2	Column3	Column4
2	**text@d_ABC**	**text@b_ABC**	**OIR**	**Type of OIR**
114	Et sur le dessus um c'est une pièce ronde, fin ronde, c'est un peu un cylindre um épais		T-1	
115		En dessus de la euh pièce verte?	T0	restricted offer
116	Brun			
117	De deux sur deux			
118	Donc c'est comme le cube d'avant mais version ronde et ya une ptite croix au milieu			
119		Ouais le truc rond ouais à quat rangées		
120	Et ça tu peux la mettre au milieu de la pièce verte qu'on vient de poser		T+1/T-1	
121		Centre cent, du coup ça dépasse euh deux euh...	T0	restricted offer
122	Ouais			
123	De chaque côté		T+1	
124		Deux devant deux derrière	T0	restricted offer
125		Ok		
126	Ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

In Extract 23, we can observe that several repair processes can overlap. In such cases, we will highlight one of them in red or adding '^' to one of them to avoid confusing the terms of each repair.

Extract 24

	Column1	Column2	Column3	Column4
2	**text@d_ABC**	**text@b_ABC**	**OIR**	**Type of OIR**
31	Ok alors c'est un modèle un peu plus complexe, la base c'est euh un mm, donc c'est une pièce verte		T-1	
32		Ok		
33	Fine			
34	Et c'est du quat sur quatre		T-1	
35		Donc une euh ouais, fine euh...	T0	restricted offer
36	C'est un carré, en fait c'est comme une plateforme un peu		T+1	
37		Y a une différence ent les vert foncé et vert clair?	T0	restricted request
38	Euh je sais pas mais en tout cas c'est plutôt le vert clair là			
39	C'est un peu le vert flashy		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

In extract 24, we have another example of two repairs overlapping.

It is important to note that each trouble source was considered as indicating a misunderstanding of a single aspect at a time. This means that when, for example, the builder asked the director two simultaneous questions involving two different aspects, such as the shape of a piece and its position, these inquiries were treated as two separate instances of trouble sources (T0). One instance requested clarification on whether it was the correct piece, and the other questioned whether it was placed in the right location.

The different types of Other-initiated repairs :

(article reference : https://doi.org/10.1371/journal.pone.0136100)

These repair initiator types go from least specific (open request) to most specific (restricted offer) in terms of the amount of information they contain about the communicative trouble and the possible solution.

Open request :

An open request indicates an issue with the trouble source, without specifying its location or nature, and seeks clarification (example: 'Hein?').

Extract 25

	Column1	Column2	Column3	Column4
2	text@d_ABC	text@b_ABC	OIR	Type of OIR
529		Euh droit	T-1	
530	Hein?		T-0	Open request
531		Genre en mode...		
532	Du p- jaune?			

(elan file : 02-11-22-NE02DI31-NE02BU31)

In extract 25, the director demonstrates that he did not understand what the builder said. However, he does not provide information about what he did not understand.

Instances such as 'I didn't understand' or 'can you repeat?' have also been categorized as open requests.

Restricted request :

It seeks specification or clarification regarding a particular aspect of the trouble source (for example: 'Qui?').

Extract 26

	Column1	Column2	Column3	Column4
2	text@d_ABC	text@b_ABC	OIR	Type of OIR
129	Et pis celle-là c'est, alors i faut la mettre um, en gros elle est en-dessus de la, de la rampe blanche		T-1	
130	Donc en-dessus des deux ptits trucs de la rampe blanche stu veux			
131	Mm à travers la pièce verte			
132		Mais à gauche ou à droite?	T0	restricted request

(elan file : 02-11-22-NE02DI30-NE02BU30)

In extract 26, the builder asks, "but left or right?" and demonstrates that it is the direction in which the Lego piece should be placed that he did not understand.

Restricted offer :

It is when a participant offers a candidate understanding for what was just said and asks for confirmation (example: 'Did you said red?')

Extract 27

	Column1	Column2	Column3	Column4
2	text@d_ABC	text@b_ABC	OIR	Type of OIR
214	Euh c'est deux pièces de deux sur quatre			
215	Une elle est rose c- pâle et l'autre elle est bleu clair		T-1	
216	Et c'est des pièces épaisses			
217		épaisses euh t'as dit rose pâle?	T0	restricted offer
218	Ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

Extract 28

	Column1	Column2	Column3	Column4
2	**text@d_ABC**	**text@b_ABC**	**OIR**	**Type of OIR**
40	Donc ça c'est la base, c'est donc cette pièce fine		T-1	
41		Quat sur quatre		
42	Um			
43		Mais du coup plat?	T0	restricted offer
44	Plat ouais		T+1	

(elan file : 02-11-22-NE02DI30-NE02BU30)

In extract 28, the builder presents a candidate understanding of what he heard. It is a restricted offer that the director can either accept or reject.

Repetitions

Every repair initiation, indicated by the occurrences of T0 in the column titled OIR, was also categorized based on whether it involved a repetition of at least one word used between the trouble source (T-1) and the initiation (T0). These repetitions aimed to provide insights into the participants' lexical alignment capability, hence we only counted word repetitions occurring between different participants. In other words, a word repeated twice by the same speaker was not considered a repetition. Repairs featuring such repetitions were marked with a cross in the column labelled 'reps'. Common articles like 'the', 'or', and 'and' were not counted as repetitions due to their frequent use, which could have skewed our results. This consideration is based on the understanding that the usage of such words does not necessarily reflect lexical alignment. It's also important to note that the use of words with a change in gender, such as 'transparent' to 'transparente' in French, was still considered a form of repetition. This approach acknowledges that even with such minor variations, the essence of the word remains the same, thereby contributing to the repetition count. This inclusion is crucial for accurately capturing the nuances of lexical alignment in conversations.

Association with visual feedback

We also categorized repair initiations (T0) based on whether they were associated with a visual cue or not. This means that each time a repair initiation was accompanied by pointing or simply by words that required visual feedback from the interlocutor to whom these initiations were directed, these initiations were marked with a cross in the column titled 'specific words'. Consequently, all occurrences of repair initiations involving phrases like 'here?', 'like this?', 'this one?', or 'on this side?' were categorized as associated with a visual cue, given the necessity of visual feedback from the other interlocutor.

Additional information

In this protocol, we mainly observed that repairs are primarily initiated verbally. However, repairs can also be initiated through facial expressions or gestures (e.g., showing a Lego piece with their hand) from the person we are interacting with. Here, we will only consider verbally initiated repairs.

Another thing to note is that it can sometimes be challenging to determine the type of operation being used or whether a participant is talking to themselves or seeking confirmation by repeating the information they were given. In such cases, it is important to consider the participants' intonation to find the answer.

Sometimes, repair initiations were represented by a sequence such as :

Builder: 'Here?'
Director: 'No.'
Builder: 'Here?'
Director: 'No.'
Builder: 'Here?'
Director: 'Yes.'

(example from a builder proposing potential placements for a Lego piece)

However, it's important to note that sometimes these requests from the builder represented an initiative taken without the director having begun to give any indications about the placement of the piece. Therefore, these sequences of 'Here?' were only counted as repairs if they followed an initial indication from the builder about where the piece should be placed

Appendix F

Luca Romanazzi

2023-12-16

Contents

LIBRARY :

```r
library(ggplot2)
library(lme4)
library(lmerTest)
library(nnet)
library(effects)
library(ggeffects)
library(dplyr)
library(gridExtra)
library(emmeans)
```

DATA :

```r
library(readxl)
data <- read_excel("FINAL_DATA.xlsx")
str(data)
```

```
## tibble [1,385 x 17] (S3: tbl_df/tbl/data.frame)
##  $ Session_Name                 : chr [1:1385] "01-11-22-NE01DI28-NE01BU28" "01-11-22-NE01DI28-NE01B
## $ Group                         : chr [1:1385] "Adults" "Adults" "Adults" "Adults" ...
## $ Condition_order               : chr [1:1385] "VI/HI" "VI/HI" "VI/HI" "VI/HI" ...
## $ Condition_Model               : chr [1:1385] "Visible" "Visible" "Visible" "Visible" ...
## $ sexe_director                 : chr [1:1385] "F" "F" "F" "F" ...
##  $ sexe_builder                 : chr [1:1385] "F" "F" "F" "F" ...
##  $ Model_Number                 : num [1:1385] 1 1 1 1 2 2 2 2 2 1 ...
##  $ totT-1                       : num [1:1385] 3 3 3 3 5 5 5 5 5 6 ...
##  $ totT0                        : num [1:1385] 4 4 4 4 5 5 5 5 5 6 ...
##  $ initiated_by                 : chr [1:1385] "BU" "BU" "BU" "BU" ...
##  $ repair_type                  : chr [1:1385] "RO" "RO" "RO" "RO" ...
##  $ repair_nb                    : num [1:1385] 1 1 2 1 2 3 4 5 6 1 ...
##  $ Reps                         : chr [1:1385] "NO" "NO" "NO" "NO" ...
##  $ di_words                     : num [1:1385] 123 123 123 123 156 156 156 156 156 291 ...
##  $ bu_words                     : num [1:1385] 16 16 16 16 17 17 17 17 17 94 ...
##  $ repairs_using_visual_feedback: chr [1:1385] "YES" "YES" "YES" "YES" ...
##  $ success_of_the_model         : chr [1:1385] "YES" "YES" "YES" "YES" ...
```

```r
summary(data)
```

```
##  Session_Name          Group            Condition_order    Condition_Model
##  Length:1385         Length:1385        Length:1385        Length:1385
##  Class :character   Class :character    Class :character    Class :character
##  Mode  :character   Mode  :character    Mode  :character    Mode  :character
##
##
##
##
##  sexe_director       sexe_builder        Model_Number        totT-1
##  Length:1385         Length:1385        Min.    :1.000    Min.   : 0.000
##  Class :character     Class :character    1st Qu.:1.000    1st Qu.: 4.000
##  Mode  :character     Mode  :character    Median :1.000    Median : 6.000
##                                           Mean    :1.458    Mean   : 5.903
##                                           3rd Qu.:2.000    3rd Qu.: 8.000
##                                           Max.    :2.000    Max.   :12.000
##
##      totT0       initiated_by       repair_type          repair_nb
##  Min.   : 0.00   Length:1385        Length:1385        Min.   : 1.000
##  1st Qu.: 7.00   Class :character   Class :character   1st Qu.: 2.000
##  Median :11.00   Mode  :character   Mode  :character   Median : 3.000
##  Mean   :11.76                                         Mean   : 3.493
##  3rd Qu.:15.00                                         3rd Qu.: 5.000
##  Max.   :31.00                                         Max.   :12.000
##                                                        NA's   :6
##      Reps              di_words         bu_words    repairs_using_visual_feedback
```

```
##  Length:1385         Min.   : 33.0   Min.   :  0   Length:1385
##  Class :character    1st Qu.:109.0   1st Qu.: 32   Class :character
##  Mode  :character    Median :171.0   Median : 83   Mode  :character
##                      Mean   :229.7   Mean   :111
##                      3rd Qu.:311.0   3rd Qu.:147
##                      Max.   :696.0   Max.   :583
##
## success_of_the_model
## Length:1385
## Class :character
## Mode  :character
##
##
##
##
```

DATA TREATMENT :

```
data <- data %>%
  mutate(Group = case_when(
    Group == "Adults" ~ "Ad",
    Group == "Older Children" ~ "Oc",
    Group == "Younger Children" ~ "Yc"
  ))

data$repair_type <- factor(data$repair_type)
data$Condition_order <- factor(data$Condition_order)
data$Condition_Model <- factor(data$Condition_Model)
data$sexe_director <- factor(data$sexe_director)
data$sexe_builder <- factor(data$sexe_builder)
data$Model_Number <- factor(data$Model_Number)
data$initiated_by <- factor(data$initiated_by)
data$Reps <- factor(data$Reps)
data$repairs_using_visual_feedback <- factor(data$repairs_using_visual_feedback)
data$success_of_the_model <- factor(data$success_of_the_model)

data$total_words <- data$bu_words + data$di_words

data$Condition_Model <- relevel(data$Condition_Model, ref = "Visible")

# CREATE A NEW COLUMN "totT_1_per_total_words" REPRESENTING THE OCCURRENCE RATE OF A REPAIR  PER WORDS
data <- data %>%
  mutate(
    totT_1_per_total_words = (`totT-1` / total_words),
  )

data_clean <- na.omit(data)

# CREATE A NEW DATASET
data_repair_permodel <- data %>%
  select(Session_Name, Group, sexe_builder, sexe_director, Condition_Model,
  Condition_order, di_words, bu_words, total_words, Model_Number,
```

```
  `totT-1`, totT_1_per_total_words,success_of_the_model) %>% distinct()
```

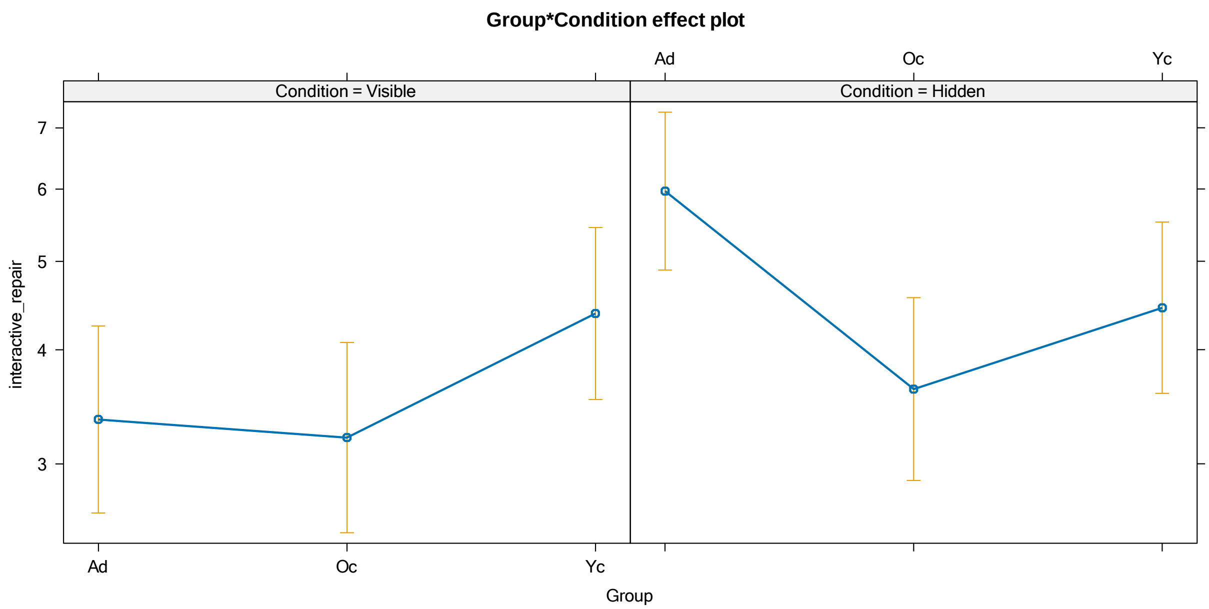
REPAIR/MODEL :

```
data_repair_permodel <- data_repair_permodel %>% rename(interactive_repair = `totT-1`)
data_repair_permodel <- data_repair_permodel %>% rename(Condition = Condition_Model)
data_repair_permodel <- data_repair_permodel %>% rename(repair_per_words = totT_1_per_total_words)
data_repair_permodel$Group <- as.factor(data_repair_permodel$Group)

# MODEL
model1 <- glmer(interactive_repair ~ Group*Condition + (1 | Group)
                + (1 | Session_Name),
                family = poisson(), data = data_repair_permodel)

summary(model1)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: poisson  ( log )
## Formula:
## interactive_repair ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
##      AIC      BIC   logLik deviance df.resid
##    810.2    835.7   -397.1    794.2      172
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.7722 -0.7580 -0.1042  0.7198
       3.1831
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 7.162e-02 2.676e-01
##  Group        (Intercept) 2.764e-10 1.662e-05
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)             1.21056    0.12036  10.058  < 2e-16 ***
## Group0c                -0.04574    0.17102  -0.267  0.78913
## GroupYc                 0.26725    0.16302   1.639  0.10115
## ConditionHidden         0.57597    0.12204   4.720 2.36e-06 ***
## Group0c:ConditionHidden -0.45375    0.18324  -2.476  0.01328 *
## GroupYc:ConditionHidden -0.56138    0.17137  -3.276  0.00105 **
## ---
## Signif. codes:  0 ' ***' 0.001 ' **' 0.01 ' *' 0.05 ' .' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) Grop0c GropYc CndtnH Gr0:CH
## Group0c     -0.698
```

```
## GroupYc      -0.734  0.517
## ConditnHddn -0.649  0.457  0.479
## GrpOc:CndtH  0.432 -0.621 -0.319 -0.666
## GrpYc:CndtH  0.462 -0.325 -0.602 -0.712  0.474
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
plot(allEffects(model1))
```




```
data_repair_permodel$Group <- factor(data_repair_permodel$Group,
                                     levels = c("Oc", "Yc", "Ad"))

model1.2 <- glmer(interactive_repair ~ Group*Condition + (1 | Group)
                  + (1 | Session_Name),
                  family = poisson(), data = data_repair_permodel)

summary(model1.2)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: poisson  ( log )
## Formula:
## interactive_repair ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
##      AIC      BIC   logLik deviance df.resid
##    810.2    835.7   -397.1    794.2      172
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.7722 -0.7580 -0.1042  0.7198
        3.1832
##
```

```
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 0.07161  0.2676
##  Group        (Intercept) 0.00000  0.0000
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)               1.16481    0.12240   9.516   <2e-16 ***
## GroupYc                   0.31299    0.16434   1.905   0.0568 .
## GroupAd                   0.04575    0.17102   0.268   0.7891
## ConditionHidden           0.12221    0.13669   0.894   0.3713
## GroupYc:ConditionHidden  -0.10760    0.18209  -0.591   0.5546
## GroupAd:ConditionHidden   0.45375    0.18324   2.476   0.0133 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropYc GropAd CndtnH GrY:CH
## GroupYc     -0.739
## GroupAd     -0.710  0.528
## ConditnHddn -0.592  0.441  0.424
## GrpYc:CndtH  0.445 -0.575 -0.318 -0.751
## GrpAd:CndtH  0.442 -0.329 -0.621 -0.746  0.560
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
data_repair_permodel$Group <- factor(data_repair_permodel$Group,
                                     levels = c("Yc", "Oc", "Ad"))

model1.3 <- glmer(interactive_repair ~ Group*Condition + (1 | Group)
                  + (1 | Session_Name),
                  family = poisson(), data = data_repair_permodel)

summary(model1.3)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: poisson  ( log )
## Formula:
## interactive_repair ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
##      AIC      BIC   logLik deviance df.resid
##    810.2    835.7   -397.1    794.2      172
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.7722 -0.7580 -0.1043  0.7198  3.1831
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 7.161e-02 2.676e-01
##  Group        (Intercept) 1.289e-10 1.135e-05
```

```
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                1.4778     0.1107  13.350  < 2e-16 ***
## GroupOc                   -0.3130     0.1643  -1.904  0.05685 .
## GroupAd                   -0.2673     0.1630  -1.639  0.10113
## ConditionHidden            0.0146     0.1203   0.121  0.90343
## GroupOc:ConditionHidden    0.1076     0.1821   0.591  0.55444
## GroupAd:ConditionHidden    0.5614     0.1714   3.276  0.00105 **
## ---
## Signif. codes:  0 ' ***'  0.001 ' **'  0.01 ' *'  0.05 ' .'  0.1 '  '  1
##
## Correlation of Fixed Effects:
##             (Intr) GropOc GropAd CndtnH GrO:CH
## GroupOc     -0.667
## GroupAd     -0.675  0.454
## ConditnHddn -0.547  0.369  0.372
## GrpOc:CndtH  0.362 -0.575 -0.246 -0.661
## GrpAd:CndtH  0.384 -0.259 -0.602 -0.702  0.464
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help(' isSingular' )
```

```
# MARGINAL MEANS
emm <- emmeans(model1, ~ Group * Condition)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition <- contrast(emm, interaction = c("pairwise"),
                                 by = "Condition",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition)
```

```
## Condition = Visible:
##  Group_pairwise estimate    SE  df z.ratio p.value
##   Ad - Oc          0.0457 0.171 Inf   0.267  0.7891
##   Ad - Yc         -0.2672 0.163 Inf  -1.639  0.1012
##   Oc - Yc         -0.3130 0.164 Inf  -1.904  0.0568
##
## Condition = Hidden:
##  Group_pairwise estimate    SE  df z.ratio p.value
##   Ad - Oc          0.4995 0.155 Inf   3.229  0.0012
##   Ad - Yc          0.2941 0.149 Inf   1.970  0.0489
##   Oc - Yc         -0.2054 0.161 Inf  -1.279  0.2007
##
## Results are given on the log (not the response) scale.
```

```
# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition2 <- contrast(emm, interaction = c("pairwise"),
                                  by = "Group",
                                  levels = list(Group = c("adults",
```

```r
                                   "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition2)
```

```
## Group = Ad:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##   Visible - Hidden   -0.5760 0.122 Inf  -4.720  <.0001
##
## Group = Oc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##   Visible - Hidden   -0.1222 0.137 Inf  -0.894  0.3712
##
## Group = Yc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##   Visible - Hidden   -0.0146 0.120 Inf  -0.121  0.9034
##
## Results are given on the log (not the response) scale.
```

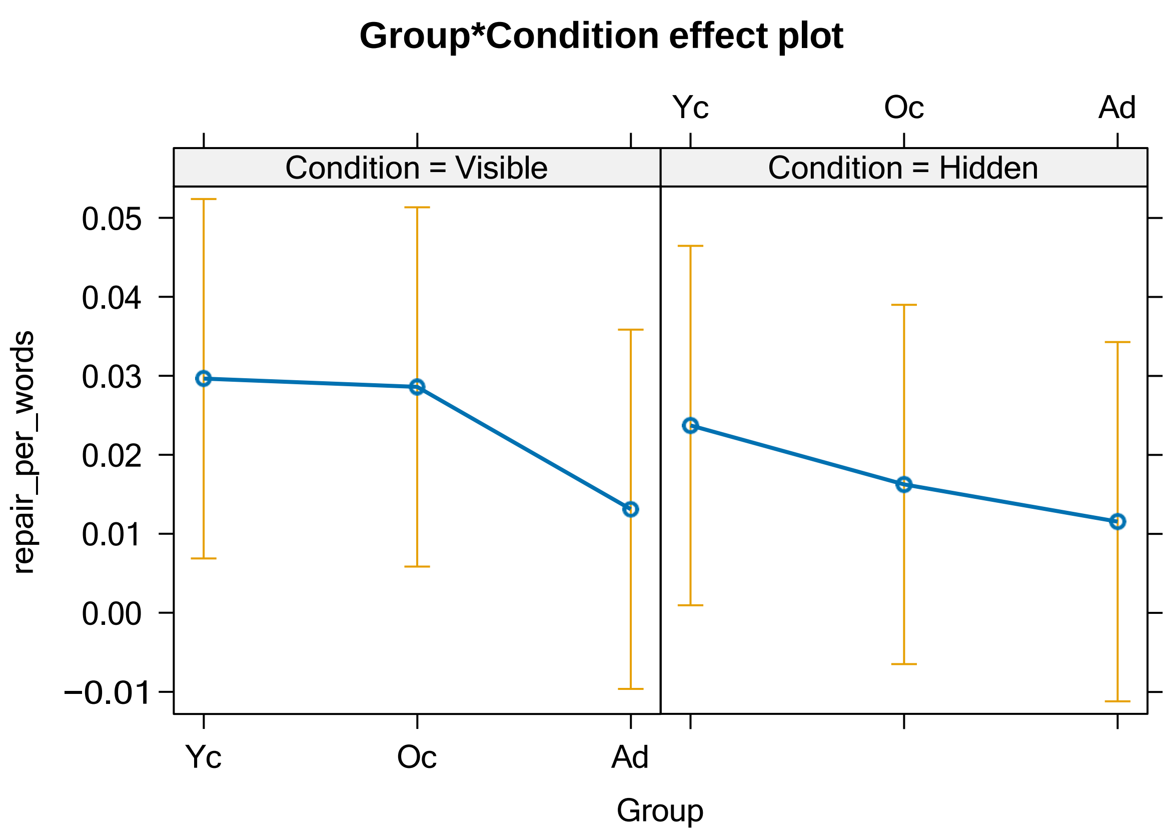
REPAIR/WORDS :

```r
# LINEAR MIXED-EFFECTS REGRESSION MODEL
model2 <- lmer(repair_per_words ~ Group*Condition + (1 | Group)
                              + (1 | Session_Name), data = data_repair_permodel)

summary(model2)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## repair_per_words ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
## REML criterion at convergence: -1030.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.1480 -0.5480 -0.1596  0.4215  3.4631
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 3.446e-05 0.005871
##  Group        (Intercept) 1.267e-04 0.011255
##  Residual                 1.155e-04 0.010748
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                           Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)               0.029653   0.011525 140.336696   2.573   0.0111 *
## GroupOc                  -0.001045   0.016298 140.336696  -0.064   0.9490
```

```
## GroupAd                      -0.016534    0.016298 140.336696  -1.014    0.3121
## ConditionHidden              -0.005928    0.002775 131.999879  -2.136    0.0345 *
## GroupOc:ConditionHidden      -0.006433    0.003925 131.999879  -1.639    0.1036
## GroupAd:ConditionHidden       0.004358    0.003925 131.999879   1.110    0.2689
## ---
## Signif. codes:  0 '***'  0.001 '**'  0.01 '*'  0.05 '.'  0.1 ' '  1
##
## Correlation of Fixed Effects:
##              (Intr) GropOc GropAd CndtnH GrO:CH
## GroupOc      -0.707
## GroupAd      -0.707  0.500
## ConditnHddn  -0.120  0.085  0.085
## GrpOc:CndtH   0.085 -0.120 -0.060 -0.707
## GrpAd:CndtH   0.085 -0.060 -0.120 -0.707  0.500
## optimizer (nloptwrap) convergence code: 0 (OK)
## unable to evaluate scaled gradient
## Model failed to converge: degenerate  Hessian with 1 negative eigenvalues
```

```
plot(allEffects(model2))
```




```
data_repair_permodel$Group <- factor(data_repair_permodel$Group,
                                     levels = c("Oc", "Yc", "Ad"))

# LINEAR MIXED-EFFECTS REGRESSION MODEL
model2.2 <- lmer(repair_per_words ~ Group*Condition + (1 | Group)
```

```
                                    + (1 | Session_Name), data = data_repair_permodel)

summary(model2.2)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula:
## repair_per_words ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
## REML criterion at convergence: -1030.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.1480 -0.5480 -0.1596  0.4215  3.4631
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 3.446e-05 0.005871
##  Group        (Intercept) 1.267e-04 0.011255
##  Residual                 1.155e-04 0.010748
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                           Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)               0.028608   0.011525 140.336698   2.482  0.01423 *
## GroupYc                   0.001045   0.016298 140.336698   0.064  0.94898
## GroupAd                  -0.015490   0.016298 140.336698  -0.950  0.34354
## ConditionHidden          -0.012361   0.002775 131.999879  -4.454 1.78e-05 ***
## GroupYc:ConditionHidden   0.006433   0.003925 131.999879   1.639  0.10359
## GroupAd:ConditionHidden   0.010790   0.003925 131.999879   2.749  0.00681 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropYc GropAd CndtnH GrY:CH
## GroupYc     -0.707
## GroupAd     -0.707  0.500
## ConditnHddn -0.120  0.085  0.085
## GrpYc:CndtH  0.085 -0.120 -0.060 -0.707
## GrpAd:CndtH  0.085 -0.060 -0.120 -0.707  0.500
## optimizer (nloptwrap) convergence code: 0 (OK)
## Model is nearly unidentifiable: large eigenvalue ratio
##  - Rescale variables?
```

```
data_repair_permodel$Group <- factor(data_repair_permodel$Group,
                                      levels = c("Ad", "Oc", "Yc"))

# LINEAR MIXED-EFFECTS REGRESSION MODEL
model2.3 <- lmer(repair_per_words ~Group*Condition + (1 | Group)
                                    + (1 | Session_Name), data = data_repair_permodel)

summary(model2.3)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite' s method [
## lmerModLmerTest]
## Formula:
## repair_per_words ~ Group * Condition + (1 | Group) + (1 | Session_Name)
##    Data: data_repair_permodel
##
## REML criterion at convergence: -1030.3
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.1480 -0.5480 -0.1596  0.4215  3.4631
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 3.446e-05 0.005871
##  Group        (Intercept) 1.267e-04 0.011255
##  Residual                 1.155e-04 0.010748
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                           Estimate Std. Error         df t value Pr(>|t|)
## (Intercept)               0.013118   0.011525 140.336697   1.138  0.25693
## GroupOc                   0.015490   0.016298 140.336696   0.950  0.34354
## GroupYc                   0.016534   0.016298 140.336696   1.014  0.31209
## ConditionHidden          -0.001570   0.002775 131.999879  -0.566  0.57243
## GroupOc:ConditionHidden  -0.010790   0.003925 131.999879  -2.749  0.00681 **
## GroupYc:ConditionHidden  -0.004358   0.003925 131.999879  -1.110  0.26890
## ---
## Signif. codes:  0 ' ***'  0.001 ' **'  0.01 ' *'  0.05 ' .'  0.1 ' '  1
##
## Correlation of Fixed Effects:
##             (Intr) GropOc GropYc CndtnH GrO:CH
## GroupOc     -0.707
## GroupYc     -0.707  0.500
## ConditnHddn -0.120  0.085  0.085
## GrpOc:CndtH  0.085 -0.120 -0.060 -0.707
## GrpYc:CndtH  0.085 -0.060 -0.120 -0.707  0.500
## optimizer (nloptwrap) convergence code: 0 (OK)
## Model is nearly unidentifiable: large eigenvalue ratio
##  - Rescale variables?
```

```
# MARGINAL MEANS
emm <- emmeans(model2, ~ Group * Condition)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition <- contrast(emm, interaction = c("pairwise"),
                                by = "Condition",
                                levels = list(Group = c("adults",
                                "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition)
```

```
## Condition = Visible:
```

```
##  Group_pairwise  estimate      SE     df  t.ratio  p.value
##  Yc - Oc          0.00104  0.0163  38963    0.064   0.9489
##  Yc - Ad          0.01653  0.0163  38963    1.014   0.3104
##  Oc - Ad          0.01549  0.0163  38963    0.950   0.3419
##
## Condition = Hidden:
##  Group_pairwise estimate      SE     df  t.ratio  p.value
##  Yc - Oc          0.00748  0.0163  38963    0.459   0.6464
##  Yc - Ad          0.01218  0.0163  38963    0.747   0.4550
##  Oc - Ad          0.00470  0.0163  38963    0.288   0.7731
##
## Degrees-of-freedom method: kenward-roger
```

```
# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition2 <- contrast(emm, interaction = c("pairwise"),
                                 by = "Group",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition2)
```

```
## Group = Yc:
##  Condition_pairwise  estimate      SE   df  t.ratio  p.value
##  Visible - Hidden     0.00593  0.00278  132   2.136   0.0345
##
## Group = Oc:
##  Condition_pairwise  estimate      SE   df  t.ratio  p.value
##  Visible - Hidden     0.01236  0.00278  132   4.454   <.0001
##
## Group = Ad:
##  Condition_pairwise  estimate      SE   df  t.ratio  p.value
##  Visible - Hidden     0.00157  0.00278  132   0.566   0.5724
##
## Degrees-of-freedom method: kenward-roger
```

REPAIR TYPE :

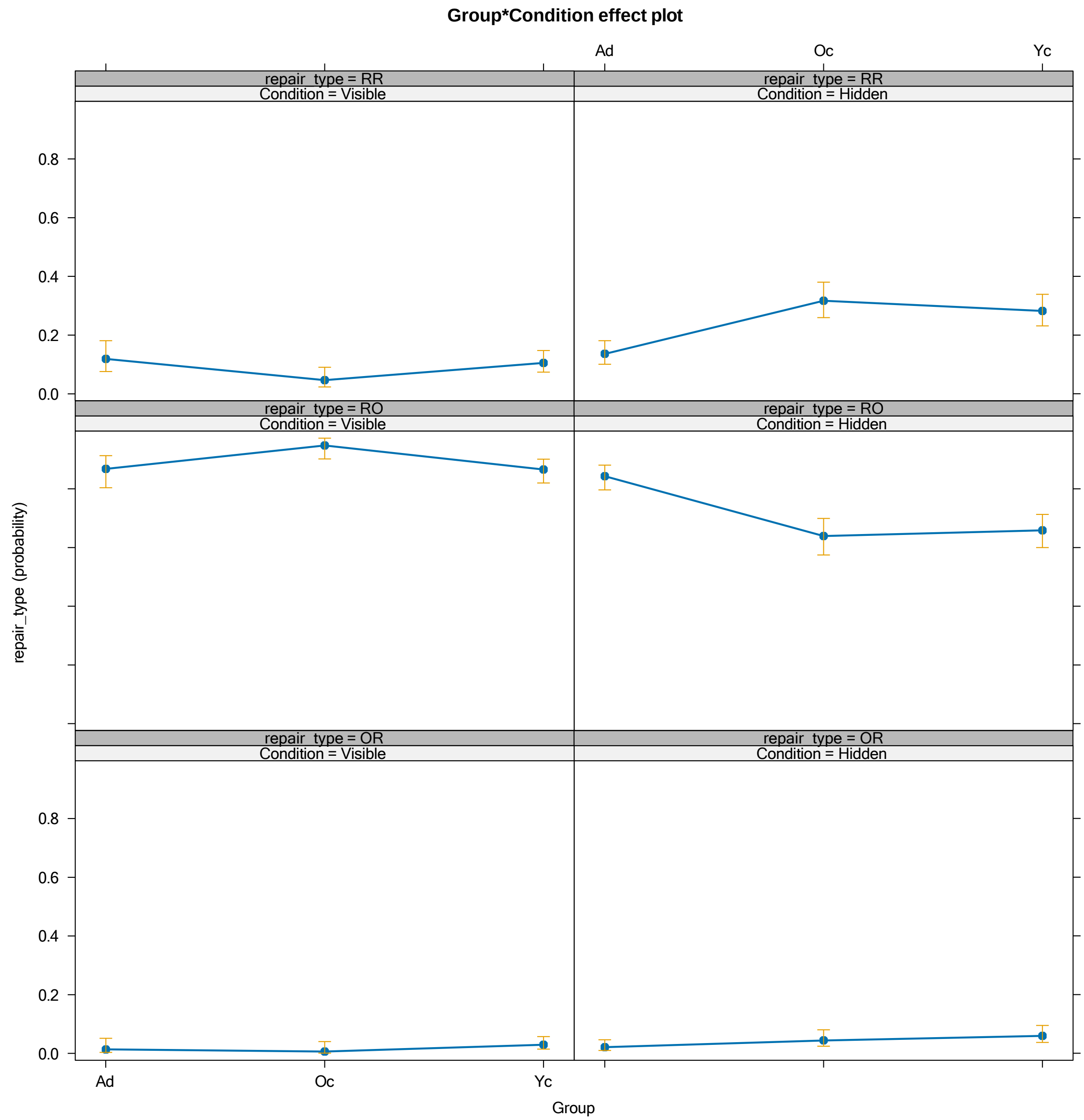
```
data_clean <- data_clean %>% rename(Condition = Condition_Model)

# CREATE A MULTINOMIAL REGRESSION MODEL
model3 <- multinom(repair_type ~ Group*Condition, data = data_clean)
```

```
## # weights:  21 (12 variable)
## initial  value 1514.986346
## iter  10 value 777.843912
## iter  20 value 768.209828
## final  value 768.209561
## converged
```

```r
summary(model3)
```

```
## Call:
## multinom(formula = repair_type ~ Group * Condition, data = data_clean)
##
## Coefficients:
##    (Intercept)    GroupOc    GroupYc ConditionHidden GroupOc:ConditionHidden
## RO    4.181686  0.9058970 -0.7888741      -0.4886120              -1.9247534
## RR    2.196857 -0.1173882 -0.9089964      -0.3250048               0.2197318
##    GroupYc:ConditionHidden
## RO              -0.5006488
## RR               0.5952858
##
## Std. Errors:
##    (Intercept)  GroupOc  GroupYc ConditionHidden GroupOc:ConditionHidden
## RO   0.7123580 1.230291 0.797906       0.8235754                1.338411
## RR   0.7452358 1.296287 0.845492       0.8646907                1.409458
##    GroupYc:ConditionHidden
## RO               0.9357487
## RR               0.9913767
##
## Residual Deviance: 1536.419
## AIC: 1560.419
```

```r
plot(allEffects(model3))
```




```r
data_clean$Group <- factor(data_clean$Group,
                           levels = c("Oc", "Yc", "Ad"))

# CREATE A MULTINOMIAL REGRESSION MODEL
model3.2 <- multinom(repair_type ~ Group*Condition, data = data_clean)
```

```
## # weights:  21 (12 variable)
## initial  value 1514.986346
## iter  10 value 774.435572
## iter  20 value 768.209571
## final  value 768.209560
## converged
```

```r
summary(model3.2)
```

```
## Call:
## multinom(formula = repair_type ~ Group * Condition, data = data_clean)
##
## Coefficients:
##     (Intercept)    GroupYc     GroupAd  ConditionHidden  GroupYc:ConditionHidden
## RO     5.087577  -1.694684  -0.9054655       -2.4134133                1.4240704
## RR     2.079352  -0.791426   0.1179445       -0.1052557                0.3754638
##    GroupAd:ConditionHidden
## RO 1.9242280
## RR              -0.2203596
##
## Std. Errors:
##     (Intercept)  GroupYc  GroupAd ConditionHidden GroupYc:ConditionHidden
## RO     1.003070 1.065533 1.230372        1.055011                1.144730
## RR     1.060653 1.133347 1.296368        1.113048                1.214094
##    GroupAd:ConditionHidden
## RO                1.338473
## RR                1.409522
##
## Residual Deviance: 1536.419
## AIC: 1560.419
```

```r
data_clean$Group <- factor(data_clean$Group,
                                    levels = c("Yc", "Oc", "Ad"))

# CREATE A MULTINOMIAL REGRESSION MODEL
model3.3 <- multinom(repair_type ~ Group*Condition, data = data_clean)
```

```
## # weights:  21 (12 variable)
## initial  value 1514.986346
## iter  10 value 771.117608
## iter  20 value 768.209565
## iter  20 value 768.209561
## iter  20 value 768.209561
## final  value 768.209561
## converged
```

```r
summary(model3.3)
```

```
## Call:
## multinom(formula = repair_type ~ Group * Condition, data = data_clean)
##
## Coefficients:
##     (Intercept)   GroupOc   GroupAd ConditionHidden GroupOc:ConditionHidden
## RO     3.392744 1.6949651 0.7892083      -0.9891024              -1.4243692
## RR     1.287811 0.7917726 0.9092824       0.2704493              -0.3758855
##    GroupAd:ConditionHidden
## RO               0.5001888
## RR              -0.5957512
##
```

```
## Std. Errors:
##    (Intercept)  GroupOc   GroupAd ConditionHidden GroupOc:ConditionHidden
## RO   0.3594328 1.065588 0.7979820       0.4442376                1.144787
## RR   0.3993392 1.133394 0.8455642       0.4849068                1.214142
##    GroupAd:ConditionHidden
## RO               0.9358132
## RR               0.9914382
##
## Residual Deviance: 1536.419
## AIC: 1560.419
```

```
# MARGINAL MEANS
emm <- emmeans(model3, ~ Group * Condition | repair_type)

# POST-HOC COMPARISONS FOR ALL REPAIR TYPES
post_hoc_results <- contrast(emm, interaction = "pairwise", by = "repair_type")

# RESULTS
print(post_hoc_results)
```

```
## repair_type = OR:
##  Group_pairwise Condition_pairwise  estimate     SE df t.ratio p.value
##  Yc - Oc        Visible - Hidden     0.03047 0.0164 12   1.855  0.0883
##  Yc - Ad        Visible - Hidden     0.02266 0.0315 12   0.720  0.4851
##  Oc - Ad        Visible - Hidden    -0.00781 0.0340 12  -0.230  0.8223
##
## repair_type = RO:
##  Group_pairwise Condition_pairwise  estimate     SE df t.ratio p.value
##  Yc - Oc        Visible - Hidden    -0.28372 0.0452 12  -6.279  <.0001
##  Yc - Ad        Visible - Hidden    -0.18257 0.0545 12  -3.351  0.0058
##  Oc - Ad        Visible - Hidden     0.10115 0.0595 12   1.699  0.1150
##
## repair_type = RR:
##  Group_pairwise Condition_pairwise  estimate     SE df t.ratio p.value
##  Yc - Oc        Visible - Hidden     0.25325 0.0436 12   5.813  0.0001
##  Yc - Ad        Visible - Hidden     0.15991 0.0499 12   3.205  0.0076
##  Oc - Ad        Visible - Hidden    -0.09333 0.0550 12  -1.698  0.1153
```

```
# MARGINAL MEANS
emm <- emmeans(model3, specs = ~ Group | repair_type)

# DATA VISIBLE
data_visible <- subset(data_clean, Condition == "Visible")

# MODEL VISIBLE
model_visible <- multinom(repair_type ~Group, data = data_visible)
```

```
## # weights:  12 (6 variable)
## initial  value 655.871536
## iter  10 value 231.961971
## final  value 231.868276
## converged
```

```r
# MARGINAL MEANS
emm_visible <- emmeans(model_visible, ~ Group | repair_type)

# PAIRWISE COMPARISONS
pairwise_comparisons <- pairs(emm_visible, adjust = "tukey")

summary(pairwise_comparisons)
```

```
## repair_type = OR:
##  contrast estimate     SE df t.ratio p.value
##  Yc - Oc   0.02325 0.0117  6   1.988  0.1958
##  Yc - Ad   0.01589 0.0138  6   1.155  0.5188
##  Oc - Ad  -0.00737 0.0110  6  -0.671  0.7878
##
## repair_type = RO:
##  contrast estimate     SE df t.ratio p.value
##  Yc - Oc  -0.08193 0.0267  6  -3.064  0.0503
##  Yc - Ad  -0.00212 0.0344  6  -0.062  0.9979
##  Oc - Ad   0.07982 0.0324  6   2.460  0.1074
##
## repair_type = RR:
##  contrast estimate     SE df t.ratio p.value
##  Yc - Oc   0.05868 0.0246  6   2.388  0.1177
##  Yc - Ad  -0.01377 0.0322  6  -0.427  0.9058
##  Oc - Ad  -0.07245 0.0309  6  -2.343  0.1247
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

```r
# DATA HIDDEN
data_hidden <- subset(data_clean, Condition == "Hidden")

# MODEL HIDDEN
model_hidden <- multinom(repair_type ~ Group, data = data_hidden)
```

```
## # weights:  12 (6 variable)
## initial  value 859.114810
## iter  10 value 537.513186
## iter  20 value 536.341366
## final  value 536.341291
## converged
```

```r
# MARGINAL MEANS
emm_hidden <- emmeans(model_hidden, ~ Group | repair_type)

# PAIRWISE COMPARISONS
pairwise_comparisons <- pairs(emm_hidden, adjust = "tukey")

summary(pairwise_comparisons)
```

```
## repair_type = OR:
##  contrast estimate     SE df t.ratio p.value
##  Yc - Oc    0.0154 0.0198  6   0.778  0.7292
```

```
##   Yc - Ad     0.0385 0.0167  6   2.302  0.1315
##   Oc - Ad     0.0231 0.0160  6   1.438  0.3816
##
## repair_type = RO:
##   contrast estimate     SE df t.ratio p.value
##   Yc - Oc     0.0192 0.0430  6   0.447  0.8977
##   Yc - Ad    -0.1847 0.0361  6  -5.121  0.0052
##   Oc - Ad    -0.2039 0.0385  6  -5.300  0.0044
##
## repair_type = RR:
##   contrast estimate     SE df t.ratio p.value
##   Yc - Oc    -0.0347 0.0413  6  -0.839  0.6948
##   Yc - Ad     0.1462 0.0341  6   4.282  0.0123
##   Oc - Ad     0.1808 0.0370  6   4.893  0.0065
##
## P value adjustment: tukey method for comparing a family of 3 estimates
```

```
# Adults" tend to use "RO" more than "Children", but the effect of the condition
# on the use of "RO" varies depending on the group. "Adults" seem less affected by the hidden
# condition than "Children", especially "Older Children", who show a more marked reduction
# in the use of "RO" under hidden condition.

# In summary, the condition appears to have a different impact on the use of repair
# types between adults and children. Specifically, children show a more pronounced
# change in the use of certain repair types under the hidden condition compared to adults"
```

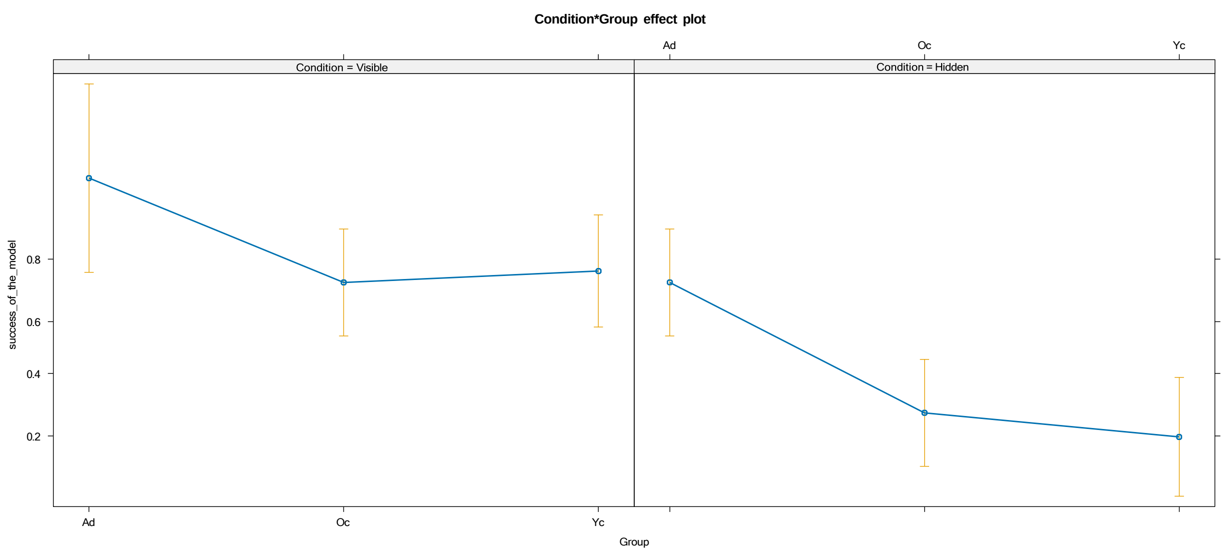
SUCCESS OF THE MODEL :

```
# MODEL
model_success <- glmer(success_of_the_model ~
                      +Condition*Group + (1 |Group) + (1 |Session_Name),
                      family = binomial, data = data_repair_permodel)

summary(model_success)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: success_of_the_model ~ +Condition * Group + (1 | Group) + (1 |
##     Session_Name)
##    Data: data_repair_permodel
##
##      AIC      BIC   logLik deviance df.resid
##    197.7    223.2    -90.8    181.7      172
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -3.7498 -0.5877  0.2667  0.5917  2.0102
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
```

```
##  Session_Name (Intercept) 0.04292  0.2072
##  Group        (Intercept) 0.00000  0.0000
## Number of obs: 180, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)                2.6577     0.7531   3.529 0.000417 ***
## ConditionHidden           -1.6360     0.8453  -1.935 0.052932 .
## GroupOc                   -1.6361     0.8488  -1.927 0.053922 .
## GroupYc                   -1.4566     0.8570  -1.700 0.089204 .
## ConditionHidden:GroupOc   -0.4072     1.0312  -0.395 0.692896
## ConditionHidden:GroupYc   -0.9643     1.0616  -0.908 0.363694
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) CndtnH GropOc GropYc CnH:GO
## ConditnHddn -0.863
## GroupOc     -0.864  0.756
## GroupYc     -0.853  0.748  0.749
## CndtnHdd:GO  0.670 -0.805 -0.801 -0.600
## CndtnHdd:GY  0.642 -0.778 -0.584 -0.787  0.661
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
plot(allEffects(model_success))
```




```
# MARGINAL MEANS
emm <- emmeans(model_success, ~ Group * Condition)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition <- contrast(emm, interaction = c("pairwise"),
                                by = "Condition",
                                levels = list(Group = c("adults",
                                "younger children", "older children")))
```

```
# SUMMARY OF COMPARISONS
summary(comp_condition)
```

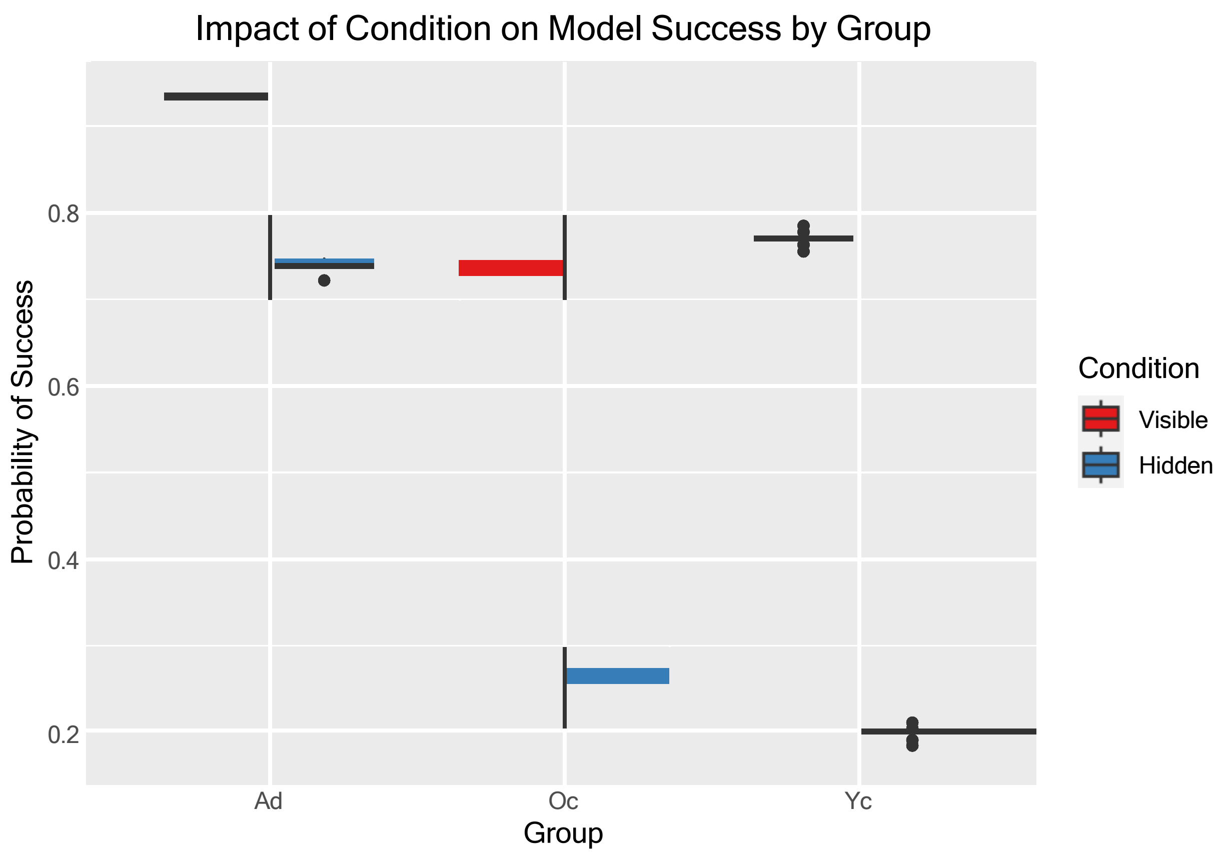
```
## Condition = Visible:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc           1.636 0.849 Inf   1.927  0.0539
##  Ad - Yc           1.457 0.857 Inf   1.700  0.0892
##  Oc - Yc          -0.179 0.605 Inf  -0.297  0.7666
##
## Condition = Hidden:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc           2.043 0.618 Inf   3.308  0.0009
##  Ad - Yc           2.421 0.655 Inf   3.694  0.0002
##  Oc - Yc           0.378 0.623 Inf   0.606  0.5444
##
## Results are given on the log odds ratio (not the response) scale.
```

```
# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition2 <- contrast(emm, interaction = c("pairwise"),
                                 by = "Group",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition2)
```

```
## Group = Ad:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden       1.64 0.845 Inf   1.935  0.0529
##
## Group = Oc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden       2.04 0.613 Inf   3.335  0.0009
##
## Group = Yc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden       2.60 0.667 Inf   3.898  0.0001
##
## Results are given on the log odds ratio (not the response) scale.
```

PLOT

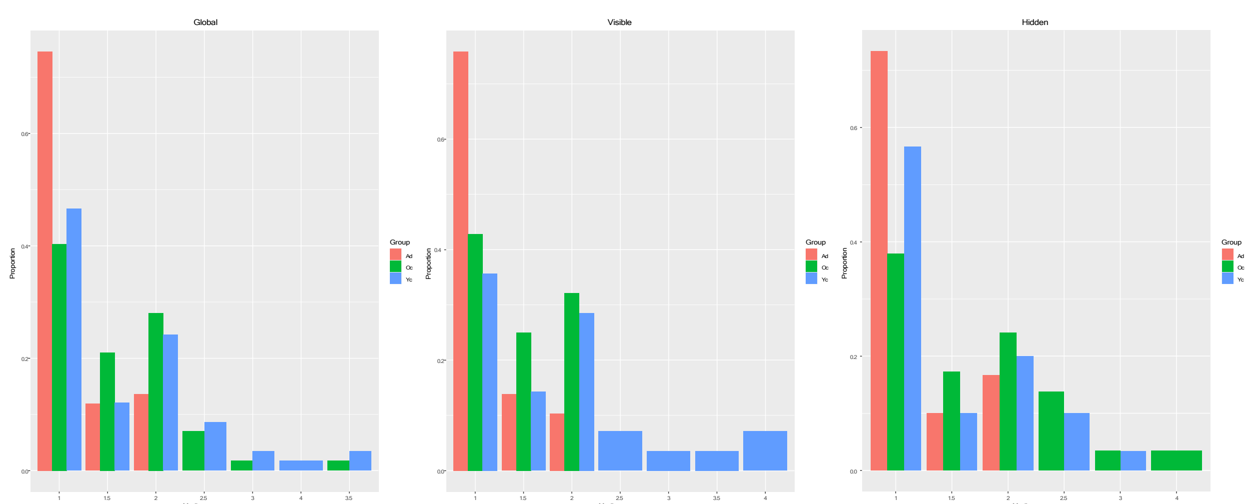
```
data_repair_permodel$predicted_prob <- predict(model_success, type = "response")

ggplot(data_repair_permodel, aes(x = Group, y = predicted_prob, fill = Condition)) +
  geom_boxplot() +
  labs(title = "Impact of Condition on Model Success by Group",
       y = "Probability of Success", x = "Group") +
  scale_fill_brewer(palette = "Set1") +
  theme(plot.title = element_text(hjust = 0.5))
```



REPAIR EFFICIENCY :

```
data_clean$Group <- factor(data_clean$Group,
                           levels = c("Ad", "Oc", "Yc"))

# CALCULATE MEDIANS OF REPAIR EFFICIENCY RATES BY MODEL
data_count <- data_clean %>%
  group_by(Group, Session_Name, sexe_builder, sexe_director, Condition, Model_Number,
           repair_nb) %>%
  summarise(count = n(), .groups = 'drop')

median_data <- data_count %>%
  group_by(Group, Session_Name, sexe_builder, sexe_director, Condition, Model_Number) %>%
  summarise(Median_count = median(count), .groups = 'drop')

# FUNCTION TO CALCULATE COUNTS, TOTALS AND CREATE A HISTOGRAM OF PROPORTIONS
create_proportions_histogram <- function(data, title) {
  # CALCULATE THE COUNT FOR EACH MEDIAN_COUNT WITHIN EACH GROUP
  counts <- data %>%
    group_by(Group, Median_count) %>%
    summarise(n = n(), .groups = 'drop')

  # CALCULATE THE TOTAL COUNT FOR EACH GROUP
```

```r
  totals <- counts %>%
    group_by(Group) %>%
    summarise(Total = sum(n), .groups = 'drop')

  # JOIN THE COUNTS WITH THE TOTALS AND CALCULATE PROPORTIONS
  proportions_data <- counts %>%
    left_join(totals, by = "Group") %>%
    mutate(Proportion = n / Total) %>%
    select(Group, Median_count, n, Total, Proportion) %>%
    ungroup()

  # CREATE A HISTOGRAM OF PROPORTIONS OF MEDIANS BY GROUPS
  ggplot(proportions_data, aes(x = as.factor(Median_count), y = Proportion, fill = Group)) +
    geom_bar(stat = "identity", position = "dodge") +
    scale_x_discrete(labels = as.character(unique(proportions_data$Median_count))) +
    labs(title = title, x = "Median_count", y = "Proportion") +
    theme(plot.title = element_text(hjust = 0.5))
}

# CREATE GLOBAL HISTOGRAM (INCLUDING BOTH VISIBLE AND HIDDEN CONDITIONS)
histogram_global  <-  create_proportions_histogram(median_data,
                      " Global")

# SPLIT THE DATA INTO TWO DATASETS: VISIBLE & HIDDEN
data_median_visible <- median_data %>% filter(Condition == "Visible")
data_median_hidden <- median_data %>% filter(Condition == "Hidden")

# CREATE HISTOGRAMS FOR VISIBLE & HIDDEN CONDITION
histogram_median_visible  <-  create_proportions_histogram(data_median_visible,
                              "Visible")
histogram_median_hidden  <-  create_proportions_histogram(data_median_hidden,
                              "Hidden")

# DISPLAY ALL HISTOGRAMS SIDE BY SIDE
grid.arrange(histogram_global, histogram_median_visible, histogram_median_hidden, ncol = 3)
```

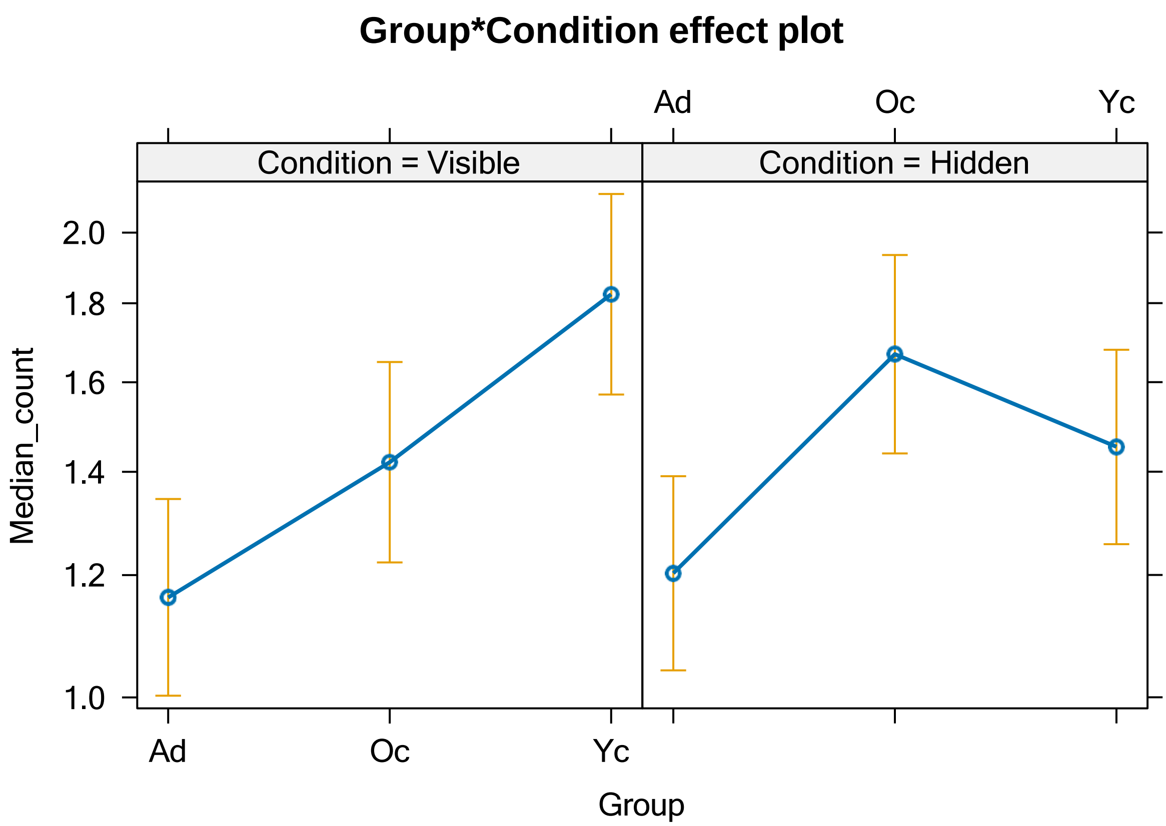


```r
# THE FOLLOWING HISTOGRAMS DEPICT THE MEDIAN COUNT OF REPAIR INITIATIONS REQUIRED
# TO SUCCESSFULLY CONCLUDE A REPAIR SEQUENCE.
# A LOWER MEDIAN COUNT REFLECTS HIGHER EFFICIENCY IN COMPLETING REPAIRS.
# THIS SUGGESTS THAT ADULTS TYPICALLY RESOLVE REPAIRS WITH GREATER EFFICIENCY.
```

```r
# MODEL 1
model_repair_efficiency1 <- glmer(Median_count ~ Group*Condition
                                  + (1 | Session_Name) + (1 | Group), family = Gamma(link = "log"),
                                  data = median_data)

summary(model_repair_efficiency1)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: Gamma  ( log )
## Formula: Median_count ~ Group * Condition + (1 | Session_Name) + (1 |
##     Group)
##    Data: median_data
##
##      AIC      BIC   logLik deviance df.resid
##    261.7    290.2   -121.9    243.7      165
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.2622 -0.7011 -0.3478  0.7067  3.3716
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 1.315e-02 1.147e-01
##  Group        (Intercept) 4.683e-09 6.843e-05
##  Residual                 1.323e-01 3.638e-01
## Number of obs: 174, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error t value Pr(>|z|)
## (Intercept)               0.14905    0.07431   2.006   0.0449 *
## GroupOc                   0.20169    0.10587   1.905   0.0568 .
## GroupYc                   0.45201    0.10607   4.261 2.03e-05 ***
## ConditionHidden           0.03589    0.08762   0.410   0.6821
## GroupOc:ConditionHidden   0.12519    0.12496   1.002   0.3164
## GroupYc:ConditionHidden  -0.26342    0.12513  -2.105   0.0353 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropOc GropYc CndtnH GrO:CH
## GroupOc     -0.699
## GroupYc     -0.700  0.490
## CondtnHddn  -0.600  0.422  0.421
## GrpOc:CndtH  0.422 -0.601 -0.295 -0.701
## GrpYc:CndtH  0.421 -0.295 -0.609 -0.700  0.491
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## Model failed to converge with max|grad| = 0.00298084 (tol = 0.002, component 1)
```

```r
plot(allEffects(model_repair_efficiency1))
```




```r
median_data$Group <- factor(median_data$Group,
                            levels = c("Oc", "Yc", "Ad"))

model_repair_efficiency2 <- glmer(Median_count ~ Group*Condition
                          + (1 | Session_Name) + (1 | Group), family = Gamma(link = "log"),
                          data = median_data)

summary(model_repair_efficiency2)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: Gamma  ( log )
## Formula: Median_count ~ Group * Condition + (1 | Session_Name) + (1 |
##     Group)
##    Data: median_data
##
##      AIC      BIC   logLik deviance df.resid
##    261.7    290.2   -121.9    243.7      165
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.2623 -0.7012 -0.3477 0.7067  3.3718
##
```

```
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 1.315e-02 1.147e-01
##  Group        (Intercept) 2.691e-11 5.187e-06
##  Residual                 1.323e-01 3.638e-01
## Number of obs: 174, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error t value Pr(>|z|)
## (Intercept)               0.35077    0.07571   4.633  3.6e-06 ***
## GroupYc                   0.25033    0.10698   2.340  0.01929 *
## GroupAd                  -0.20174    0.10587  -1.905  0.05672 .
## ConditionHidden           0.16101    0.08910   1.807  0.07075 .
## GroupYc:ConditionHidden  -0.38856    0.12616  -3.080  0.00207 **
## GroupAd:ConditionHidden  -0.12506    0.12496  -1.001  0.31693
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropYc GropAd CndtnH GrY:CH
## GroupYc     -0.706
## GroupAd     -0.712  0.503
## ConditnHddn -0.597  0.423  0.428
## GrpYc:CndtH  0.422 -0.608 -0.302 -0.706
## GrpAd:CndtH  0.426 -0.302 -0.601 -0.713  0.503
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
median_data$Group <- factor(median_data$Group,
                            levels = c("Yc", "Oc", "Ad"))

model_repair_efficiency3 <- glmer(Median_count ~ Group*Condition
                          + (1 | Session_Name) + (1 | Group), family = Gamma(link = "log"),
                          data = median_data)

summary(model_repair_efficiency3)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: Gamma  ( log )
## Formula: Median_count ~ Group * Condition + (1 | Session_Name) + (1 |
##     Group)
##    Data: median_data
##
##      AIC      BIC   logLik deviance df.resid
##    261.7    290.2   -121.9    243.7      165
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.2623 -0.7013 -0.3477  0.7067  3.3718
##
## Random effects:
##  Groups       Name        Variance  Std.Dev.
##  Session_Name (Intercept) 1.316e-02 1.147e-01
```

```
##  Group        (Intercept) 2.071e-09 4.551e-05
##  Residual                 1.323e-01 3.638e-01
## Number of obs: 174, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                         Estimate Std. Error t value Pr(>|z|)
## (Intercept)              0.60107    0.07579   7.931 2.18e-15 ***
## GroupOc                 -0.25026    0.10699  -2.339  0.01933 *
## GroupAd                 -0.45207    0.10608  -4.262 2.03e-05 ***
## ConditionHidden         -0.22755    0.08934  -2.547  0.01086 *
## GroupOc:ConditionHidden  0.38851    0.12616   3.079  0.00207 **
## GroupAd:ConditionHidden  0.26351    0.12513   2.106  0.03521 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropOc GropAd CndtnH GrO:CH
## GroupOc     -0.707
## GroupAd     -0.714  0.506
## ConditnHddn -0.616  0.437  0.440
## GrpOc:CndtH  0.436 -0.608 -0.311 -0.708
## GrpAd:CndtH  0.440 -0.312 -0.609 -0.714  0.505
```

```
# MARGINAL MEANS
emm <- emmeans(model_repair_efficiency1, ~ Group * Condition)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition <- contrast(emm, interaction = c("pairwise"),
                                 by = "Condition",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition)
```

```
## Condition = Visible:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc          -0.202 0.106 Inf  -1.905  0.0568
##  Ad - Yc          -0.452 0.106 Inf  -4.261  <.0001
##  Oc - Yc          -0.250 0.107 Inf  -2.340  0.0193
##
## Condition = Hidden:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc          -0.327 0.105 Inf  -3.127  0.0018
##  Ad - Yc          -0.189 0.104 Inf  -1.819  0.0689
##  Oc - Yc           0.138 0.105 Inf   1.321  0.1863
##
## Results are given on the log (not the response) scale.
```

```
# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition2 <- contrast(emm, interaction = c("pairwise"),
                                  by = "Group",
                                 levels = list(Group = c("adults",
```

```r
                                    "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition2)
```

```
## Group = Ad:
##  Condition_pairwise estimate     SE  df z.ratio p.value
##  Visible - Hidden    -0.0359 0.0876 Inf  -0.410  0.6821
##
## Group = Oc:
##  Condition_pairwise estimate     SE  df z.ratio p.value
##  Visible - Hidden    -0.1611 0.0891 Inf  -1.808  0.0706
##
## Group = Yc:
##  Condition_pairwise estimate     SE  df z.ratio p.value
##  Visible - Hidden     0.2275 0.0893 Inf   2.547  0.0109
##
## Results are given on the log (not the response) scale.
```

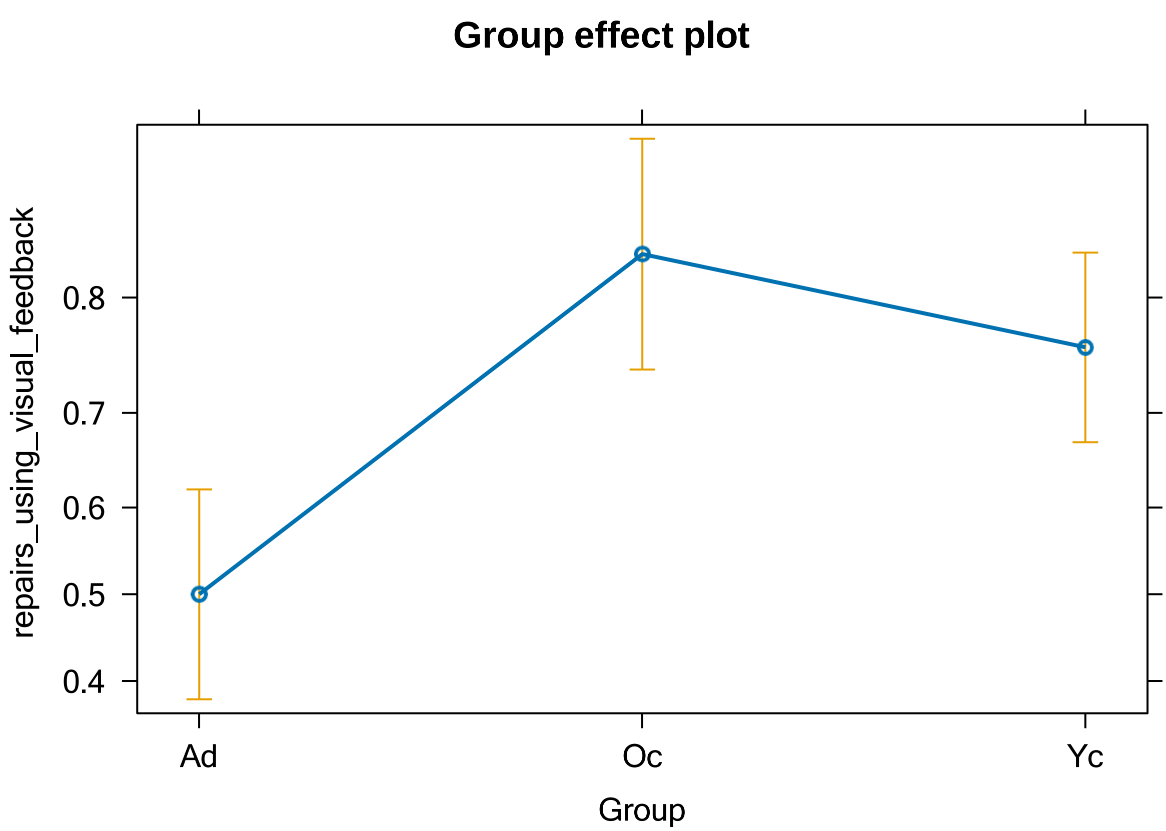
REPAIRS USING VISUAL FEEDBACK :

```r
data_clean_visible <- data_clean %>% filter(Condition == "Visible")
data_clean_hidden <- data_clean %>% filter(Condition == "Hidden")

# MODEL
model_visual_cues_visible1 <- glmer(repairs_using_visual_feedback ~ Group + (1 | Group)
                                  + (1 | Session_Name), family = binomial,
                                  data = data_clean_visible)

summary(model_visual_cues_visible1)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## repairs_using_visual_feedback ~ Group + (1 | Group) + (1 | Session_Name)
##    Data: data_clean_visible
##
##      AIC      BIC   logLik deviance df.resid
##    683.1    705.0   -336.5    673.1      592
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.4615 -0.9064  0.4552  0.6311  1.2788
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 0.3854   0.6208
##  Group        (Intercept) 0.0000   0.0000
## Number of obs: 597, groups:  Session_Name, 44; Group, 3
```

```
##
## Fixed effects:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept) 0.0003159  0.2501320   0.001 0.998992
## GroupOc     1.5893130  0.3705275   4.289 1.79e-05 ***
## GroupYc     1.1535989  0.3349249   3.444 0.000572 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##         (Intr) GropOc
## GroupOc -0.670
## GroupYc -0.738  0.500
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```r
plot(allEffects(model_visual_cues_visible1))
```




```r
data_clean_visible$Group <- factor(data_clean_visible$Group,
                                  levels = c("Oc", "Yc", "Ad"))

model_visual_cues_visible2 <- glmer(repairs_using_visual_feedback ~ Group + (1 | Group)
                                  + (1 | Session_Name), family = binomial,
                                  data = data_clean_visible)

summary(model_visual_cues_visible2)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## repairs_using_visual_feedback ~ Group + (1 | Group) + (1 | Session_Name)
##    Data: data_clean_visible
##
##      AIC      BIC   logLik deviance df.resid
##    683.1    705.0   -336.5    673.1      592
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.4615 -0.9064  0.4552  0.6311   1.2788
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 3.854e-01 6.208e-01
##  Group        (Intercept) 1.807e-10 1.344e-05
## Number of obs: 597, groups:  Session_Name, 44; Group, 3
##
## Fixed effects:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   1.5896     0.2751   5.778 7.55e-09 ***
## GroupYc      -0.4357     0.3539  -1.231    0.218
## GroupAd      -1.5893     0.3705  -4.289 1.79e-05 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##         (Intr) GropYc
## GroupYc -0.770
## GroupAd -0.738  0.573
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
data_clean_visible$Group <- factor(data_clean_visible$Group,
                                   levels = c("Yc", "Oc", "Ad"))

model_visual_cues_visible3 <- glmer(repairs_using_visual_feedback ~ Group + (1 | Group)
                                 + (1 | Session_Name), family = binomial,
                                 data = data_clean_visible)

summary(model_visual_cues_visible3)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## repairs_using_visual_feedback ~ Group + (1 | Group) + (1 | Session_Name)
##    Data: data_clean_visible
##
```

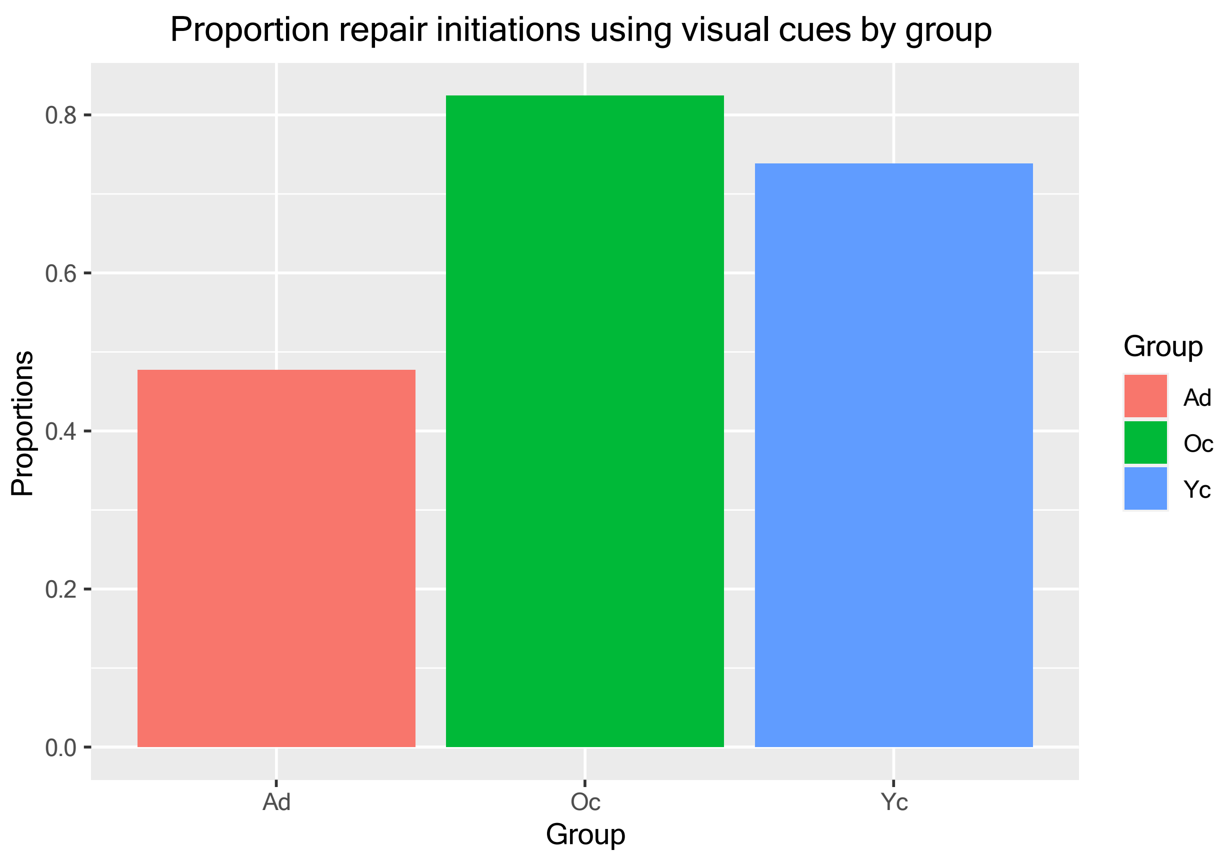
```
##      AIC      BIC   logLik deviance df.resid
##    683.1    705.0   -336.5    673.1      592
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.4615 -0.9064  0.4552  0.6311  1.2788
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 0.3854   0.6208
##  Group        (Intercept) 0.0000   0.0000
## Number of obs: 597, groups:  Session_Name, 44; Group, 3
##
## Fixed effects:
##             Estimate Std. Error z value Pr(>|z|)
## (Intercept)   1.1539     0.2260   5.106 3.29e-07 ***
## GroupOc       0.4357     0.3539   1.231 0.218313
## GroupAd      -1.1536     0.3349  -3.444 0.000572 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##         (Intr) GropOc
## GroupOc -0.629
## GroupAd -0.665  0.422
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
data_clean_visible$predicted_prob <- predict(model_visual_cues_visible1, type = "response")

# MARGINAL MEANS
emmtest <- emmeans(model_visual_cues_visible1, ~ Group)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_conditiontest <- contrast(emmtest, method = "pairwise")

# SUMMARY OF COMPARISONS
summary(comp_conditiontest)
```

```
##  contrast estimate    SE  df z.ratio p.value
##  Ad - Oc    -1.589 0.371 Inf  -4.289  0.0001
##  Ad - Yc    -1.154 0.335 Inf  -3.444  0.0017
##  Oc - Yc     0.436 0.354 Inf   1.231  0.4348
##
## Results are given on the log odds ratio (not the response) scale.
## P value adjustment: tukey method for comparing a family of 3 estimates
```

```
data_clean_visible$Group <- factor(data_clean_visible$Group,
                                   levels = c("Ad", "Oc", "Yc"))

# CALCULATE THE PROPORTIONS OF REPAIRS USING VISUAL CUES
proportions_data <- data_clean_visible %>%
  group_by(Group) %>%
```

```r
  summarise(Proportion_YES = mean(repairs_using_visual_feedback == "YES"))

# BAR CHART OF THE PROPORTIONS
ggplot(proportions_data, aes(x = Group, y = Proportion_YES, fill = Group)) +
  geom_bar(stat = "identity") +
  labs(title = "Proportion repair initiations using visual cues by group",
       x = "Group", y = "Proportions") +
  theme(plot.title = element_text(hjust = 0.5))
```




```r
# NUMBER OF REPAIR INITIATIONS USING VISUAL CUES IN THE HIDDEN CONDITION BY GROUP
count_yes <- table(data_clean_hidden$Group[data_clean_hidden$repairs_using_visual_feedback == "YES"])

print(count_yes)
```

```
##
## Ad Oc Yc
##  0  7 13
```

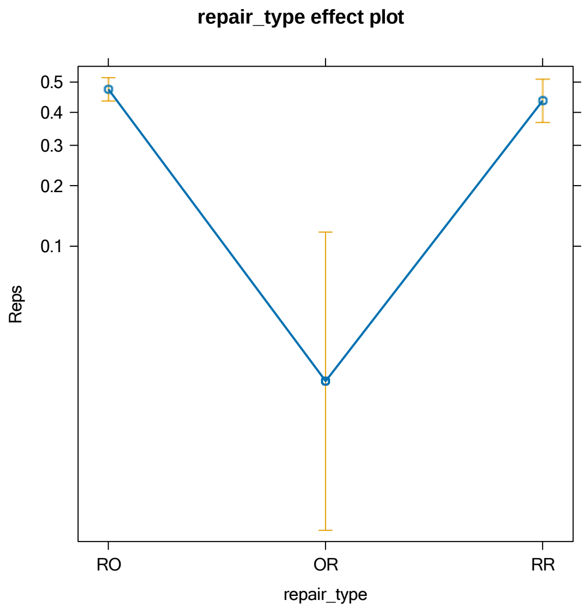
REPETITIONS :

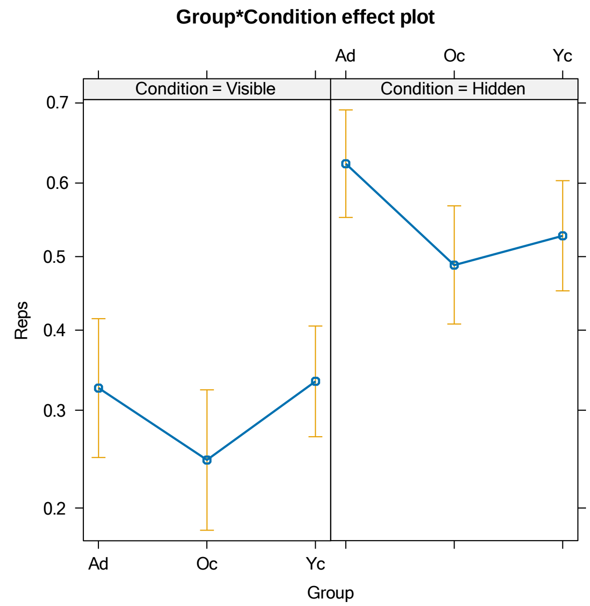
```r
data_clean$repair_type <- relevel(data_clean$repair_type, ref = "RO")
```

```r
# MODEL
model_reps1 <- glmer(Reps ~ Group*Condition + repair_type +
                     (1 | Group) + (1 | Session_Name), family = binomial, data = data_clean)

summary(model_reps1)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## Reps ~ Group * Condition + repair_type + (1 | Group) + (1 | Session_Name)
##    Data: data_clean
##
##      AIC      BIC   logLik deviance df.resid
##   1781.5   1833.8   -880.8   1761.5     1369
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.5728 -0.8332 -0.5268  0.8971  6.4685
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 8.334e-02 2.887e-01
##  Group        (Intercept) 1.614e-09 4.018e-05
## Number of obs: 1379, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error  z value Pr(>|z|)
## (Intercept)              -0.57566    0.19311   -2.981 0.002873 **
## GroupOc                  -0.39685    0.27353   -1.451 0.146817
## GroupYc                   0.03701    0.24396    0.152 0.879412
## ConditionHidden           1.23707    0.21778    5.680 1.34e-08 ***
## repair_typeOR            -3.90530    1.01921   -3.832 0.000127 ***
## repair_typeRR            -0.15308    0.15393   -0.994 0.320007
## GroupOc:ConditionHidden  -0.16172    0.31726   -0.510 0.610244
## GroupYc:ConditionHidden  -0.43445    0.28579   -1.520 0.128470
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropOc GropYc CndtnH rpr_OR rpr_RR GrO:CH
## GroupOc     -0.705
## GroupYc     -0.780  0.550
## ConditnHddn -0.738  0.524  0.578
## repar_typOR -0.003 -0.001 -0.006 -0.021
## repar_typRR -0.091  0.040  0.012 -0.024  0.038
## GrpOc:CndtH  0.517 -0.728 -0.399 -0.680 -0.001 -0.120
## GrpYc:CndtH  0.567 -0.398 -0.685 -0.753 -0.007 -0.088  0.529
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```r
plot(allEffects(model_reps1))
```






```r
data_clean$Group <- factor(data_clean$Group,
                           levels = c("Oc", "Yc", "Ad"))

model_reps2 <- glmer(Reps ~ Group*Condition + repair_type +
                     (1 | Group) + (1 | Session_Name), family = binomial, data = data_clean)

summary(model_reps2)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## Reps ~ Group * Condition + repair_type + (1 | Group) + (1 | Session_Name)
##    Data: data_clean
##
##      AIC      BIC   logLik deviance df.resid
##   1781.5   1833.8   -880.8   1761.5     1369
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.5728 -0.8332 -0.5268  0.8971
       6.464
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 8.333e-02 2.887e-01
##  Group        (Intercept) 1.993e-09 4.464e-05
## Number of obs: 1379, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                            Estimate Std. Error z value Pr(>|z|)
## (Intercept)                 -0.9726     0.1939  -5.015 5.29e-07 ***
## GroupYc                      0.4341     0.2470   1.758 0.078803 .
```

```
## GroupAd                   0.3970     0.2735    1.452 0.146613
## ConditionHidden           1.0753     0.2325    4.624 3.76e-06 ***
## repair_typeOR            -3.9046     1.0189   -3.832 0.000127 ***
## repair_typeRR            -0.1531     0.1539   -0.995 0.319947
## GroupYc:ConditionHidden  -0.2729     0.2939   -0.928 0.353162
## GroupAd:ConditionHidden   0.1616     0.3173    0.509 0.610454
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) GropYc GropAd CndtnH rpr_OR rpr_RR GrY:CH
## GroupYc     -0.786
## GroupAd     -0.708  0.565
## ConditnHddn -0.696  0.554  0.503
## repar_typOR -0.005 -0.004  0.001 -0.021
## repar_typRR -0.035 -0.032 -0.040 -0.187  0.038
## GrpYc:CndtH  0.556 -0.674 -0.399 -0.769 -0.006  0.044
## GrpAd:CndtH  0.512 -0.412 -0.728 -0.727  0.001  0.120  0.565
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```r
data_clean$Group <- factor(data_clean$Group,
                           levels = c("Yc", "Oc", "Ad"))

model_reps3 <- glmer(Reps ~ Group*Condition + repair_type +
                   (1 | Group) + (1 | Session_Name), family = binomial, data = data_clean)

summary(model_reps3)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula:
## Reps ~ Group * Condition + repair_type + (1 | Group) + (1 | Session_Name)
##    Data: data_clean
##
##      AIC      BIC   logLik deviance df.resid
##   1781.5   1833.8   -880.8   1761.5     1369
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.5728 -0.8332 -0.5267  0.8971  6.4657
##
## Random effects:
##  Groups       Name        Variance Std.Dev.
##  Session_Name (Intercept) 0.08336  0.2887
##  Group        (Intercept) 0.00000  0.0000
## Number of obs: 1379, groups:  Session_Name, 45; Group, 3
##
## Fixed effects:
##                          Estimate Std. Error z value Pr(>|z|)
## (Intercept)              -0.53859    0.15279  -3.525 0.000423 ***
## GroupOc                  -0.43408    0.24695  -1.758 0.078796 .
## GroupAd                  -0.03689    0.24395  -0.151 0.879789
## ConditionHidden           0.80258    0.18806   4.268 1.98e-05 ***
```

```
## repair_typeOR             -3.90441     1.01862  -3.833 0.000127 ***
## repair_typeRR             -0.15302     0.15394  -0.994 0.320185
## GroupOc:ConditionHidden    0.27273     0.29394   0.928 0.353482
## GroupAd:ConditionHidden    0.43426     0.28578   1.520 0.128621
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##              (Intr) GropOc GropAd CndtnH rpr_OR rpr_RR GrO:CH
## GroupOc      -0.619
## GroupAd      -0.611  0.379
## ConditnHddn  -0.583  0.368  0.371
## repar_typOR  -0.012  0.004  0.006 -0.035
## repar_typRR  -0.097  0.032 -0.012 -0.162  0.038
## GrpOc:CndtH   0.383 -0.673 -0.235 -0.612  0.006 -0.044
## GrpAd:CndtH   0.376 -0.235 -0.685 -0.648  0.007  0.088  0.401
## optimizer (Nelder_Mead) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

```
# MARGINAL MEANS
emm <- emmeans(model_reps1, ~ Group * Condition)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition <- contrast(emm, interaction = c("pairwise"),
                                 by = "Condition",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition)
```

```
## Condition = Visible:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc           0.397 0.274 Inf   1.451  0.1468
##  Ad - Yc          -0.037 0.244 Inf  -0.152  0.8794
##  Oc - Yc          -0.434 0.247 Inf  -1.757  0.0789
##
## Condition = Hidden:
##  Group_pairwise estimate    SE  df z.ratio p.value
##  Ad - Oc           0.559 0.222 Inf   2.521  0.0117
##  Ad - Yc           0.397 0.214 Inf   1.859  0.0631
##  Oc - Yc          -0.161 0.223 Inf  -0.723  0.4694
##
## Results are averaged over the levels of: repair_type
## Results are given on the log odds ratio (not the response) scale.
```

```
# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition2 <- contrast(emm, interaction = c("pairwise"),
                                 by = "Group",
                                 levels = list(Group = c("adults",
                                 "younger children", "older children")))

# SUMMARY OF COMPARISONS
summary(comp_condition2)
```

```
## Group = Ad:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden    -1.237 0.218 Inf  -5.680  <.0001
##
## Group = Oc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden    -1.075 0.233 Inf  -4.625  <.0001
##
## Group = Yc:
##  Condition_pairwise estimate    SE  df z.ratio p.value
##  Visible - Hidden    -0.803 0.188 Inf  -4.268  <.0001
##
## Results are averaged over the levels of: repair_type
## Results are given on the log odds ratio (not the response) scale.
```

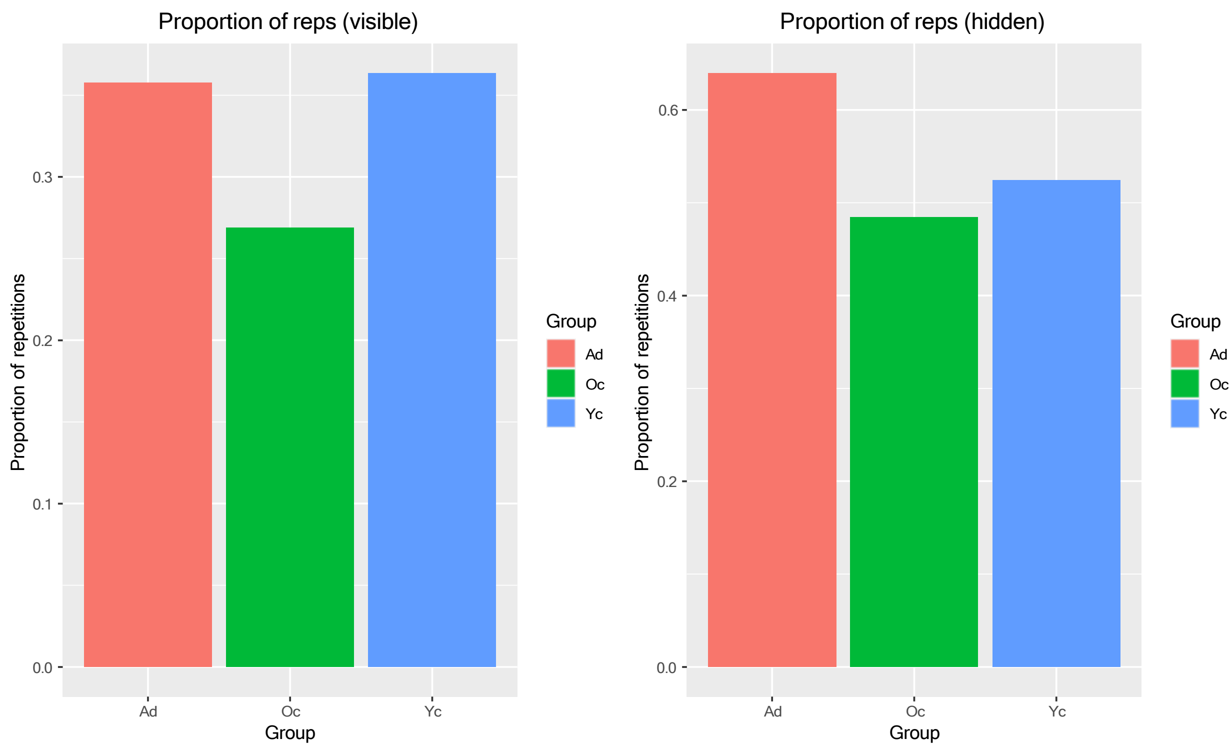
```r
# MARGINAL MEANS
emm2 <- emmeans(model_reps1, ~ repair_type)

# CONTRAST COMPARISONS BETWEEN GROUPS FOR A SPECIFIC CONDITION
comp_condition3 <- contrast(emm2, method = "pairwise",
                            levels = c(repair_type = c("RR", "RO", "OR")))

# SUMMARY OF COMPARISONS
summary(comp_condition3)
```

```
##  contrast estimate    SE  df z.ratio p.value
##  RO - OR     3.905 1.019 Inf   3.832  0.0004
##  RO - RR     0.153 0.154 Inf   0.994  0.5804
##  OR - RR    -3.752 1.025 Inf  -3.661  0.0007
##
## Results are averaged over the levels of: Group, Condition
## Results are given on the log odds ratio (not the response) scale.
## P value adjustment: tukey method for comparing a family of 3 estimates
```

PLOT

```r
# CALCULATE THE PROPORTIONS OF REPETITIONS BY GROUP IN THE VISIBLE CONDITION
proportions_data_reps_vi <- data_clean_visible %>%
  group_by(Group) %>%
  summarise(Proportion_YES = mean(Reps == "YES"))

# CREATE A BAR CHART OF PROPORTIONS OF REPETITIONS BY GROUP IN THE VISIBLE CONDITION
ggplot1 <- ggplot(proportions_data_reps_vi, aes(x = Group, y = Proportion_YES, fill = Group)) +
  geom_bar(stat = "identity") +
  labs(title = "Proportion of reps (visible)",
       x = "Group", y = "Proportion of repetitions") +
  theme(plot.title = element_text(hjust = 0.5))

# CALCULATE THE PROPORTIONS OF REPETITIONS BY GROUP IN THE HIDDEN CONDITION
proportions_data_reps_hi <- data_clean_hidden %>%
  group_by(Group) %>%
  summarise(Proportion_YES = mean(Reps == "YES"))
```

```r
#CREATE A BAR CHART OF PROPORTIONS OF REPETITIONS BY GROUP IN THE HIDDEN CONDITION
ggplot2 <- ggplot(proportions_data_reps_hi, aes(x = Group, y = Proportion_YES, fill = Group)) +
  geom_bar(stat = "identity") +
  labs(title = "Proportion of reps (hidden)",
       x = "Group", y = "Proportion of repetitions") +
  theme(plot.title = element_text(hjust = 0.5))

grid.arrange(ggplot1, ggplot2, ncol = 2)
```



Session Info :

```r
sessionInfo()
```

```
## R version 4.3.1 (2023-06-16 ucrt)
## Platform: x86_64-w64-mingw32/x64 (64-bit)
## Running under: Windows 11 x64 (build 22631)
##
## Matrix products: default
##
##
## locale:
## [1] LC_COLLATE=French_Switzerland.utf8  LC_CTYPE=French_Switzerland.utf8
## [3] LC_MONETARY=French_Switzerland.utf8 LC_NUMERIC=C
## [5] LC_TIME=French_Switzerland.utf8
##
```

```
## time zone: Europe/Zurich
## tzcode source: internal
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] readxl_1.4.3    emmeans_1.9.0   gridExtra_2.3   dplyr_1.1.3
##  [5] ggeffects_1.3.4 effects_4.2-2   carData_3.0-5   nnet_7.3-19
##  [9] lmerTest_3.1-3  lme4_1.1-35.1   Matrix_1.6-2    ggplot2_3.4.4
##
## loaded via a namespace (and not attached):
##  [1] gtable_0.3.4        xfun_0.40           insight_0.19.7
##  [4] lattice_0.21-8      numDeriv_2016.8-1.1 vctrs_0.6.4
##  [7] tools_4.3.1         generics_0.1.3      parallel_4.3.1
## [10] pbkrtest_0.5.2      sandwich_3.0-2      tibble_3.2.1
## [13] fansi_1.0.5         pkgconfig_2.0.3     RColorBrewer_1.1-3
## [16] lifecycle_1.0.3     farver_2.1.1        compiler_4.3.1
## [19] munsell_0.5.0       mitools_2.4         codetools_0.2-19
## [22] survey_4.2-1        htmltools_0.5.7     yaml_2.3.7
## [25] tidyr_1.3.0         pillar_1.9.0        nloptr_2.0.3
## [28] MASS_7.3-60         boot_1.3-28.1       multcomp_1.4-25
## [31] nlme_3.1-162        tidyselect_1.2.0    digest_0.6.33
## [34] mvtnorm_1.2-3       purrr_1.0.2         labeling_0.4.3
## [37] splines_4.3.1       fastmap_1.1.1       grid_4.3.1
## [40] colorspace_2.1-0    cli_3.6.1           magrittr_2.0.3
## [43] survival_3.5-5      utf8_1.2.4          broom_1.0.5
## [46] TH.data_1.1-2       withr_2.5.1         backports_1.4.1
## [49] scales_1.2.1        estimability_1.4.1  rmarkdown_2.25
## [52] cellranger_1.1.0    zoo_1.8-12          coda_0.19-4
## [55] evaluate_0.22       knitr_1.44          rlang_1.1.1
## [58] Rcpp_1.0.11         xtable_1.8-4        glue_1.6.2
## [61] DBI_1.1.3           rstudioapi_0.15.0   minqa_1.2.6
## [64] R6_2.5.1
```