Universidad del Desarrollo
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From Childhood to Adulthood: The Influence of Social Preferences and Theory of Mind on Decision-Making in Social Negotiation

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LIST OF ABBREVIATIONS

EFs – Executive Functions

mPFC – Medial Prefrontal Cortex

ND – Neurodivergent Development

STS – Superior Temporal Sulcus

TD – Typical Development

ToM – Theory of Mind

TPJ – Temporoparietal Junction

UG – Ultimatum Game

ABSTRACT

This thesis examines how social decision-making develops from childhood through adulthood, focusing on fairness, feedback integration, and individual strategies in the Ultimatum Game (UG). Drawing on theories of Theory of Mind (ToM) and executive functions (EFs), the central hypothesis is that social decision-making becomes more stable, cooperative, and fairness-oriented with age. Study 1 systematically reviewed available research regarding the development of ToM, EFs, neurodevelopment and social preferences. Study 2 examined whether social feedback (acceptance vs. rejection) and prior adjustments influenced proposer strategies, with the hypotheses that (a) feedback affects immediate adjustments, (b) reliance on feedback decreases with age, and (c) negotiation strategies consolidate into identifiable behavioral clusters. Findings revealed that feedback prompted short-term adjustments, but these effects did not persist across rounds. Instead, age-related patterns were most evident in baseline offers: children showed greater variability, adolescents leaned toward competitive strategies, and adults prioritized fairness and stability. Results suggest that while social feedback shapes momentary decisions, long-term strategies are guided more by stable individual preferences and developmental changes in ToM and EFs. By integrating fairness norms with age-related differences in stability and cooperation, this thesis contributes to understanding how social negotiation strategies mature over time.

1. GENERAL INTRODUCTION

Human social interactions depend on the ability to interpret and predict others' mental states, a capacity known as Theory of Mind (ToM). ToM enables individuals to attribute beliefs, desires, and emotions to others, guiding cooperation, fairness judgments, and strategic decision-making (Carlson & Zelazo, 2021; Poulin-Dubois, 2020). While ToM emerges in early childhood, its development extends into adolescence and adulthood, shaped by cognitive maturation, social experiences, and neurobiological changes (Giovagnoli, 2019). Both cognitive ToM (understanding beliefs and knowledge) and affective ToM (understanding emotions) are crucial for negotiation, moral reasoning, and fairness-based decision-making, domains where individuals must weigh their own outcomes against those of others.

A central construct in this process is that of social preferences, defined as systematic individual differences in how people balance self-interest with regard for the outcomes of others (Fehr & Schmidt, 1999). Social preferences include tendencies toward fairness, reciprocity, altruism, and competition, and they critically shape how individuals behave in social dilemmas such as bargaining and resource sharing. Developmental research shows that these preferences evolve with age: children often rely on simple fairness heuristics, sometimes alternating between cooperative generosity and self-interested behavior (Blake et al., 2015). Adolescents, by contrast, are more likely to engage in competitive and risk-taking strategies, influenced by heightened sensitivity to peer dynamics and social status (Kumar et al., 2022; Białecka-Pikul et al., 2021). Adults, in turn, typically adopt more stable, fairness-oriented strategies, reflecting greater strategic consistency and alignment with normative expectations (Marchetti et al., 2019).

Study 1 of this thesis synthesized research on the development of ToM and its interaction with executive functions (EFs), social preferences, and neural mechanisms. EFs—such as inhibitory control, working memory, and cognitive flexibility—are central in supporting ToM abilities across different age groups and neurodevelopmental conditions (Zelazo & Müller, 2002; Lecce et al., 2019). This review also examined how fairness norms and decision-making strategies change across development, identifying brain regions including the medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), and superior temporal sulcus (STS) as central to ToM processing (Sai et al., 2021).

Building on this foundation, Study 2 empirically investigated how individuals across childhood, adolescence, and adulthood integrate social preferences into negotiation strategies using the Ultimatum Game (UG). This study tested whether fairness-based decision-making is dynamically adjusted in response to feedback (acceptance vs. rejection of offers) or whether it reflects more stable developmental tendencies. The findings revealed meaningful age-related differences: children exhibited greater variability and exploratory behavior, adolescents displayed heightened competitiveness, and adults showed the most stable and fairness-oriented strategies. Notably, however, feedback sensitivity was minimal across all groups, suggesting that fairness preferences may be more stable than previously assumed and are not strongly shaped by short-term reinforcement learning.

Together, these two studies fill an important gap in literature. While prior research has extensively examined ToM and fairness in isolation, few studies have systematically integrated these constructs with developmental differences in feedback sensitivity and strategic stability across childhood, adolescence, and adulthood. By combining a theoretical review with empirical modeling, this thesis provides a developmental framework that links ToM, EFs, and social preferences to the evolution of social decision-making. The general hypothesis guiding this work is that social negotiation strategies mature over development, shifting from variable and exploratory (children), through competitive and risk-taking (adolescents), to stable and fairness-oriented (adults). This progression reflects not only cognitive and neurobiological maturation but also the increasing integration of others' outcomes into decision-making.

In doing so, the thesis contributes to developmental psychology, behavioral economics, and cognitive neuroscience, with implications for education, clinical practice, and cross-cultural studies. It highlights that while immediate feedback exerts limited influence, developmental changes in fairness preferences and strategic stability are central to understanding how individuals negotiate social exchanges across the lifespan.

2. STUDY 1: THEORY OF MIND, NEURODEVELOPMENT AND SOCIAL PREFERENCES: A SYSTEMATIC REVIEW

2.1. Introduction

Social cognition, particularly the ability to attribute mental states (such as beliefs, desires, intentions, and emotions) to oneself and others and to understand that these states may differ from one's own, plays a fundamental role in human interaction and development (Premack & Woodruff, 1978). This capacity, known as Theory of Mind (ToM), is essential for understanding others' beliefs, desires, and intentions, facilitating cooperation, empathy, and moral reasoning. Research on ToM has spanned across multiple disciplines, including developmental psychology, neuroscience, and cognitive science, investigating how ToM emerges and evolves throughout the lifespan (Peterson & Wellman, 2019). While ToM typically develops in early childhood, its progression is influenced by neurocognitive factors, executive functions (EFs), and social experiences, which contribute to individual differences in ToM proficiency across different populations (Dumontheil et al., 2010; Gabriel et al., 2021). Furthermore, challenges in ToM are widely documented in neurodivergent populations, such as individuals with Autism Spectrum Disorder (ASD) and Attention Deficit Hyperactivity Disorder (ADHD), where alterations in social cognition impact social interactions and decision-making (Cantio et al., 2018; Jelili et al., 2022). Understanding how ToM is shaped by neurodevelopmental conditions, social preferences, and neurobiological mechanisms is essential for refining theoretical models and intervention strategies.

ToM reasoning can be understood in different orders of recursion, which vary in complexity. First-order ToM involves recognizing that another person can hold a belief different from reality (e.g., “She thinks the toy is in the box”). Second-order ToM requires reasoning about what one person believes about another’s belief (e.g., “He thinks that she thinks the toy is in the box”). Higher-order ToM (third order and beyond) involves increasingly abstract recursive reasoning, such as predicting what multiple individuals believe about each other’s intentions in complex social interactions. These distinctions are important because developmental studies show that while first-order ToM emerges in early childhood, higher-order ToM requires more advanced executive and linguistic skills and develops more gradually through adolescence.

The development of ToM is closely linked to EFs, including working memory, inhibitory control, and cognitive flexibility, which facilitate the ability to manage competing perspectives and process complex social information (Hughes & Ensor, 2008; Huyder et al., 2017). As children mature, executive function improvements contribute to the refinement of perspective-taking abilities, supporting the gradual transition from simple to more sophisticated ToM reasoning (Taylor et al., 2013). However, the interplay between ToM and EF extends beyond childhood, as EFs play a crucial role in maintaining ToM abilities in aging populations. Research suggests that cognitive ToM, which involves reasoning about beliefs and intentions, declines with age due to executive function challenges, while affective ToM, related to emotional understanding, remains relatively stable (Fischer et al., 2017; Bottiroli et al., 2016). The extent to which these cognitive changes affect social decision-making, fairness considerations, and moral reasoning remains a critical question in developmental and social psychology.

In addition to its developmental trajectory, ToM significantly influences social preferences, which refer to the ways individuals value fairness, cooperation, equity, and reciprocity in social interactions. These preferences are often studied using experimental economic paradigms. For example, in the Dictator Game (DG), one player unilaterally decides how to divide resources, revealing generosity or selfishness. In the UG, one player proposes a division, and the responder can accept or reject it, introducing fairness and reciprocity considerations. Variants such as the Mini-Ultimatum Game (MUG) manipulate contextual fairness cues. Classic false-belief tasks test the ability to recognize when another person holds an incorrect belief, and more advanced paradigms (e.g., Strange Stories, Faux Pas Test) assess higher-order ToM. Together, these tasks provide insight into how ToM supports fairness judgments, cooperation, and moral reasoning.

Studies show that while younger children often rely on rigid, self-serving fairness heuristics, their ability to incorporate ToM-based reasoning becomes more refined with age, as they grow more capable of handling complex social stimuli and abstract considerations, such as others' intentions, perspectives, and contextual factors in resource distribution (Overgaauw et al., 2012; Bueno-Guerra et al., 2016). In adulthood, fairness preferences remain influential but are modulated by emotional regulation and strategic thinking, with older adults exhibiting a greater tendency toward prosocial behavior and generosity (Bailey et al., 2013; Girardi et al., 2018). However, in clinical populations, ToM alterations can lead to atypical moral reasoning, particularly in ASD, where difficulties in distinguishing between intentions and outcomes contribute to alterations in fairness judgments (Moran et al., 2011; Ringshaw et al., 2022).

At a neurobiological level, ToM is supported by a distributed network of brain regions, including the medial prefrontal cortex (mPFC), temporoparietal junction (TPJ), and superior temporal sulcus (STS), which facilitate perspective-taking and mental state attribution (Dufour et al., 2013; Richardson et al., 2020). The maturation of these neural circuits is crucial for ToM development, with functional connectivity between social cognition regions strengthening throughout childhood and adolescence (Xiao et al., 2019). However, neuroimaging findings suggest that ToM alterations in ASD may not always correspond to reduced brain activation, but rather reflect atypical neural processing strategies, emphasizing the need for further research into neurodevelopmental differences in social cognition (Dufour et al., 2013; Richardson et al., 2020). Additionally, hormonal influences on ToM, such as the effects of testosterone on mental state reasoning, have been identified, with evidence suggesting age-dependent differences in how hormones modulate social cognition (Grainger et al., 2021).

This systematic review aims to synthesize behavioral and neuroimaging findings related to ToM, neurodevelopment, and social preferences across various developmental stages in both neurotypical and neurodivergent populations. Specifically, it examines (1) how ToM develops across the lifespan, (2) the role of EFs in shaping ToM abilities, (3) the impact of ToM on social decision-making and moral reasoning, and (4) the neural mechanisms underlying ToM and its variability in different populations. By integrating findings from experimental studies spanning 2000 to 2025, this review seeks to provide a comprehensive understanding of the cognitive, social, and neurobiological factors influencing ToM development and its implications for social cognition.

2.2. METHODOLOGY

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021) to ensure methodological transparency and reproducibility. It aims to synthesize behavioral and neuroimaging findings related to ToM, neurodevelopment, and social preferences across various developmental stages in both neurotypical and neurodivergent developing populations.

A comprehensive literature search was conducted between January and February 2025 using Web of Science (WoS), PubMed, and Scopus, restricting results to peer-reviewed experimental studies published between 2000 and 2025 in English and Spanish. The search strategy included a combination of keywords and Boolean operators to refine results, focusing on ToM (e.g., *mentalizing, false belief, perspective-taking*), neurodevelopment (e.g., *brain maturation, ASD, ADHD*), social preferences (e.g., *UG, social decision-making, moral reasoning*), and neuroimaging methods (e.g., *fMRI, EEG, brain activity*). Boolean operators (AND, OR) were used to optimize specificity and filter studies relevant to the research focus. The terms used for the search are described in Table 1**.**

Table 1 Searched for terms

Topic	Controlled Vocabulary	Natural Vocabulary
Population	("Adolescents"[MeSH] OR "Adults"[MeSH] OR "Aging"[MeSH] OR "Brain Development"[MeSH] OR "Childhood"[MeSH] OR "Neurodevelopmental Disorders"[MeSH] OR "Neurodevelopmental Conditions"[TIAB])	("Adolescents" OR "Adults" OR "Aging" OR "Brain Development" OR "Childhood" OR "Neurodevelopmental Disorders" OR "Neurodevelopmental Conditions")

Area of interest	("Cognition"[MeSH] OR "Executive Function"[MeSH] OR "Decision Making"[MeSH] OR "Learning"[MeSH] OR "Mentalizing"[TIAB] OR "Strategic Behavior"[TIAB]) AND ("Age Groups"[TIAB] OR "Neurotypical"[TIAB] OR "Atypical Development"[TIAB] OR "Social Negotiation"[TIAB] OR "Strategic Behavior"[TIAB])	("Cognition" OR "Executive Function" OR "Decision Making" OR "Learning" OR "Mentalizing" OR "Strategic Behavior") AND ("Age Groups" OR "Neurotypical" OR "Atypical Development" OR "Social Negotiation" OR "Strategic Behavior")
Outcome	("Social Cognition"[MeSH] OR "Social Preferences"[TIAB] OR "Theory of Mind"[TIAB] OR "Social Decision Making"[TIAB] OR "Ultimatum Game"[TIAB] OR "Mentalization"[TIAB])	("Social Cognition" OR "Social Preferences" OR "Theory of Mind" OR "Social Decision Making" OR "Ultimatum Game" OR "Mentalization")

Studies were selected using a three-phase screening process, which involved assessing articles based on their title, abstract, and full-text review. To be included, studies had to examine ToM development and its influence on social decision-making, moral reasoning, and social preferences across children, adolescents, and adults. Eligible studies included both neurotypical and neurodivergent developing populations (e.g., ASD, ADHD, intellectual disabilities) and employed empirical research methods (quantitative, qualitative, or mixed). Only studies utilizing experimental, observational, or longitudinal designs were considered, particularly those incorporating behavioral and/or neuroimaging measures such as false-belief tasks, the UG, Dictator Game, and social decision paradigms. Additionally, studies employing functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG), and other neuroimaging techniques to investigate the neural underpinnings of ToM and social preferences were included. The review prioritized studies published between 2000 and 2025, though seminal works outside this period were considered when relevant.

Studies were excluded if they did not focus on ToM, social preferences, or neurodevelopment or if they involved non-human subjects (e.g., animal models, AI simulations) without direct comparisons to human cognition. Research examining that did not directly measure ToM, social preferences, or neurodevelopment were excluded. Additionally, non-peer-reviewed sources (e.g., grey literature, preprints, conference abstracts, opinion papers) and studies solely focused on neural mechanisms (e.g., mirror neurons) without behavioral or social measures were excluded. Articles published before 2000, unless considered seminal, and studies not available in English or Spanish or lacking accessible translations were also excluded. Inclusion criteria and exclusion criteria are synthesized in Table 2.

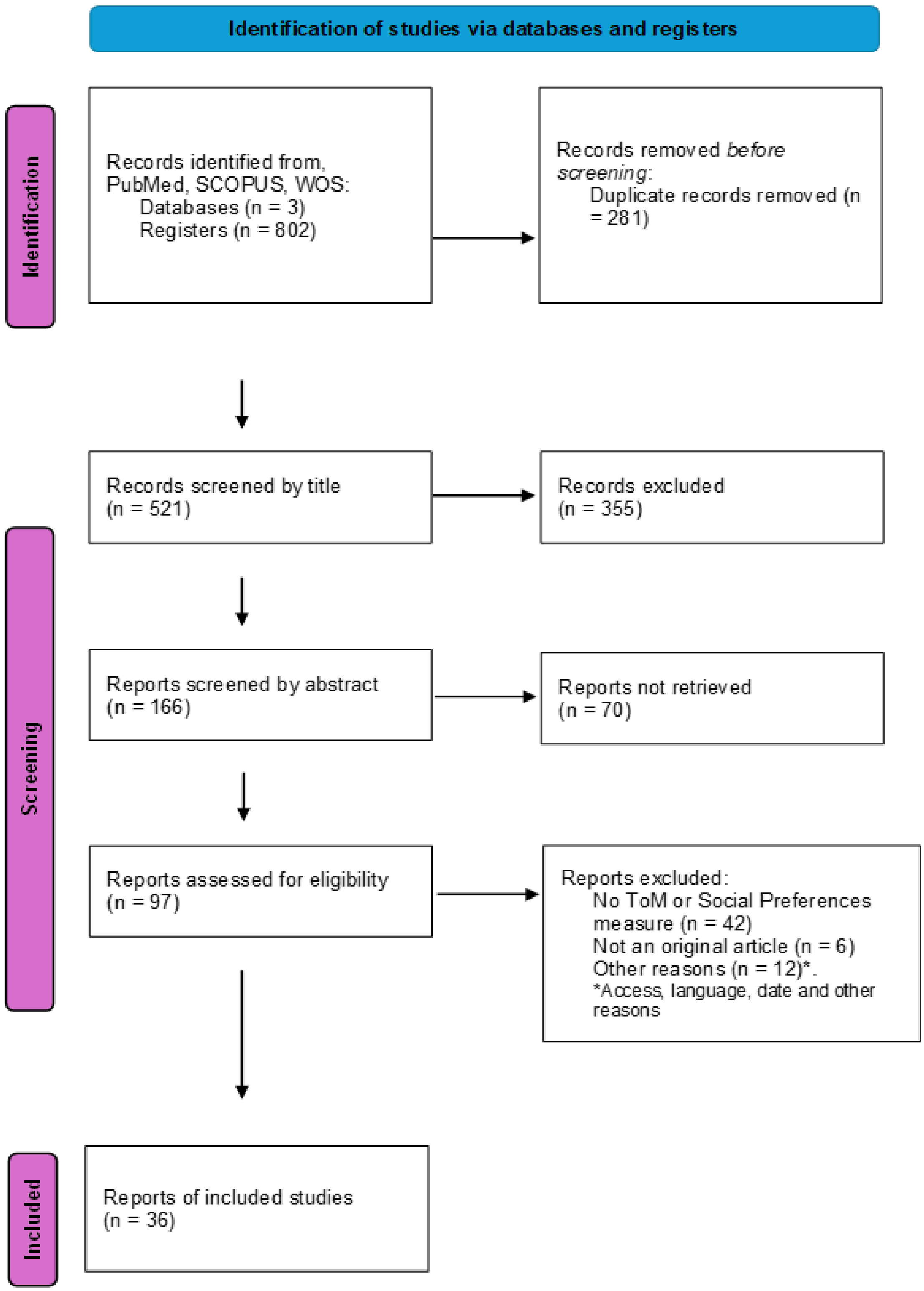
Table 2 Inclusion criteria and exclusion criteria

Inclusion Criteria	Studies on Theory of Mind (ToM), social preferences, and neurodevelopment across all ages and neurodevelopmental conditions (e.g., ASD, ADHD). Eligible studies examine ToM's role in social decision-making, moral reasoning, and preference formation, using behavioral, neuroimaging (fMRI, EEG), experimental, or longitudinal methods. Measures include false-belief tasks, the Ultimatum Game, and neural activity patterns.

Exclusion Criteria	Excluded studies lacked a ToM, social preference, or neurodevelopment focus, involved non-human models, or solely examined unrelated cognitive functions (e.g., attention). Case reports, theoretical papers, reviews and meta-analysis, and non-peer-reviewed sources were also excluded. Research on neural mechanisms without behavioral context was excluded

The study selection process was conducted by an independent reviewer using a three-step screening protocol: (1) Title screening, where irrelevant articles were excluded; (2) Abstract screening, where eligibility was assessed based on the abstract; and (3) Full-text review, where the final selection was made. For included studies, a standardized data extraction form was used to collect study characteristics (author, year and sample size), participant demographics (age groups, typically/neurodivergent developing classification), study design (ToM tasks, social preference measures, neuroimaging methods), and key findings related to ToM, neurodevelopment, and social decision-making. Neuroimaging data, including brain regions involved (e.g., temporoparietal junction, medial prefrontal cortex), and social preference outcomes (e.g., rejection rates, fairness evaluations, strategic behavior) were also extracted. The PRISMA flowchart was used to visualize the selection process (Diagram 1), tracking the total records identified, screened, excluded (with reasons), and final studies included in the review.

Diagram 1 Flow diagram of search and selection



2.3. RESULTS

This systematic review identified 36 studies examining the relationship between ToM, neurodevelopment, and social preferences across various age groups and neurodevelopmental profiles. Studies were categorized based on their primary methodological approach, where some overlap, including ToM assessments (n=26), social preference measures (n=14), executive function measures (n=10), and neuroimaging techniques (n=11). These studies spanned children, adolescents, and adults, with comparisons between typically and neurodivergent developing (TD and ND, respectively) populations, such as individuals with ASD and ADHD.

The majority of studies focused on ToM assessments, employing tasks like the Social Attribution Task (SAT), Reading the Mind in the Eyes Test (RMET), Strange Stories task, and the Faux Pas Test, among others, to evaluate cognitive and affective aspects of ToM across different developmental stages (*Babarczy et al., 2024; Bottiroli et al., 2016; Cantio et al., 2018; Castelli et al., 2010; Castelli et al., 2014; Cavallini et al., 2013; Dufour et al., 2013; Dumontheil et al., 2010; Fischer et al., 2017; Gabriel et al., 2021; Girardi et al., 2018; Grainger et al., 2021; Gunther Moor et al., 2012; Hughes & Ensor, 2008; Huyder et al., 2017; Jelili et al., 2022; Moran et al., 2011; Pagni et al., 2020; Peters & Schulz, 2022; Peterson & Wellman, 2019; Rahman et al., 2021; Richardson et al., 2020; Ringshaw et al., 2022; Taylor et al., 2013; Xiao et al., 2019*). A significant portion of the studies examined social preferences, particularly using economic decision-making tasks including the UG and Dictator Game, among others, which provided insights into fairness considerations and strategic behavior across age groups *(Bailey et al., 2013; Billeke et al., 2014; Bueno-Guerra et al., 2016; Castelli et al., 2010; Castelli et al., 2014; Girardi et al., 2018; Güroğlu et al., 2011; Harlé & Sanfey, 2012; Konovalov et al., 2021; Moran et al., 2011; Overgaauw et al., 2012; Ringshaw et al., 2022; Sazhin et al., 2024; Steinmann et al., 2014*).

Neuroimaging studies utilized fMRI and EEG to explore the neural underpinnings of ToM and social decision-making, highlighting key brain regions such as the TPJ, mPFC, and anterior insula (*Billeke et al., 2014; Dufour et al., 2013; Gunther Moor et al., 2012; Güroglu et al., 2011; Harlé & Sanfey, 2012; Konovalov et al., 2021; Richardson et al., 2020; Sazhin et al., 2024; Soto-Icaza et al., 2019; Steinmann et al., 2014; Xiao et al., 2019*). Additionally, some studies examined EFs measures, assessing their role in supporting ToM abilities and social reasoning across development (*Babarczy et al., 2024; Bottiroli et al., 2016; Cantio et al., 2018; Cavallini et al., 2013; Gabriel et al., 2021; Garcia-Molina & Clemente-Estevan, 2019; Hughes & Ensor, 2008; Huyder et al., 2017; Soto-Icaza et al., 2019; Taylor et al., 2013*).

In the following sections, the results of the studies will be presented and analyzed considering the outcomes of the measures used (ToM, social preferences, EF and neuroimaging), comparing them relative to the participants characteristics and age groups (TD, ND, children, adolescents or adults). All studies' general results in this systematic review can be found summarized in Table 3, by Authors, Title, Age groups, Number of participants, TD or ND and measures reported.

Table 3 General results

Reference	Title	Age group(s)	Number of Participants	Group(s) of participants	Measures reported
Babarczy et al., 2024	Variability of theory of mind versus pragmatic ability in typical and atypical development	Children	12 TD, 16 DLD (DLD group excluded from analysis)	TD, ASD, ADHD, and DLD	SAT-MC-I-II (Social Attribution Task - Multiple Choice), KOBAK Test (Pragmatic Comprehension)
Bailey et al., 2013	Age-Related Differences in Social Economic Decision Making: The Ultimatum Game	Young adults, Older adults	69 (35 young, 34 older)	TD	Ultimatum Game
Billeke et al., 2014	Someone has to give in: Theta oscillations correlate with adaptive behavior in social bargaining	Young adults	39 (22 main task, 17 control task)	TD	Ultimatum Game, EEG

Bottiroli et al., 2016	Theory of Mind in aging: Comparing cognitive and affective components in the faux pas test	Young adults, Older adults	62 (20 young, 22 young-old, 20 old-old)	TD	Faux Pas Test, Inhibition, Working Memory, Word Fluency
Bueno-Guerra et al., 2016	Do sex and age affect strategic behavior and inequity aversion in children?	Children	478 (ages 6 and 10)	TD	Mini-Ultimatum Game
Cantio et al., 2018	Do Cognitive Deficits Persist Into Adolescence In Autism?	Adolescents	31	Both (ASD and TD)	Strange Stories, Executive Functions (CANTAB)
Castelli et al., 2010	Fairness and intentionality in childrenâ€™s decision-making	Children	177 (ages 5-10)	TD	Ultimatum Game, False Belief Task
Castelli et al., 2014	What is fair for you? Judgments and decisions about fairness and Theory of Mind	Children	157	TD	Ultimatum Game, Second-Order False Belief Task
Cavallini et al., 2013	Beyond False Belief: Theory of Mind in young, young-old, and old-old adults	Young adults, Older adults	86 (30 young, 27 young-old, 29 old-old)	TD	Strange Stories Task, MMSE, Working Memory
Dufour et al., 2013	Similar Brain Activation during False Belief Tasks in a Large Sample of Adults with and without Autism	Adults	493 (462 TD, 31 ASD)	Both (ASD and TD)	False Belief Task, fMRI
Dumontheil et al., 2010	Online usage of theory of mind continues to develop in late adolescence	Adolescents, Adults	177	TD	Perspective-taking Task

Fischer et al., 2017	Age Differences in Cognitive and Affective Theory of Mind	Young adults, Older adults	171 (86 young, 85 older)	TD	RMET, Faux Pas, Pulse Pressure
Gabriel et al., 2021	Cognitive and affective Theory of Mind in adolescence	Adolescents	643	TD	False Belief Task, Cognitive and Affective ToM, Attention, Working Memory, Language Comprehensio n, Figural Intelligence
Garcia-Molina & Clemente-Estevan, 2019	Autism and Faux Pas: Influences of Presentation Modality and Working Memory	Children	60 (30 ASD, 30 TD)	Both (ASD and TD)	Faux Pas Test, Working Memory
Girardi et al., 2018	Theory of Mind and the Ultimatum Game in healthy adult aging	Young adults, Older adults	52 (22 young, 30 older)	TD	Ultimatum Game, Faux Pas
Grainger et al., 2021	The relationship between testosterone and social cognition in younger and older adults	Young adults, Older adults	158 (80 young, 78 older)	TD	RMET, Testosterone Levels
Gunther Moor et al., 2012	Neurodevelopment al changes of reading the mind in the eyes	Children, Adolescents, Young adults	55	TD	RMET, fMRI
Güroglu et al., 2011	Dissociable brain networks involved in development of fairness considerations	Children, Adolescents, Young adults	68 (ages 10, 13, 15, 20)	TD	Mini-Ultimatum Game, fMRI

Harlé & Sanfey, 2012	Social economic decision-making across the lifespan: An fMRI investigation	Young adults, Older adults	38 (18 young, 20 older)	TD	Ultimatum Game, fMRI
Hughes & Ensor, 2008	Does executive function matter for preschoolersâ€™ problem behaviors?	Children	122	TD	Executive Functions, False Belief Task
Huyder et al., 2017	The relationship between childrenâ€™s executive functioning, theory of mind, and verbal skills	Children	Varied (5-12 years)	TD	Inhibitory Control, Working Memory, Planning, Verbal, ToM Measures
Jelili et al., 2022	Assessment of Theory of Mind in Tunisian verbal children with autism spectrum disorder	Children	62 (32 ASD, 30 TD)	Both (ASD and TD)	ToM Instrument (TSSI)
Konovalov et al., 2021	Dissecting functional contributions of the social brain to strategic behavior	Young adults	60	TD	Strategic Card-prediction Game, fMRI
Moran et al., 2011	Impaired theory of mind for moral judgment in high-functioning autism	Adults	TD and ASD (exact n not stated)	Both (ASD and TD)	Moral Judgment, False Belief Task
Overgaauw et al., 2012	Fairness considerations when I know more than you do	Children, Young adults	101	TD	Ultimatum Game
Pagni et al., 2020	Social Cognition in Autism Spectrum Disorder Across the Adult Lifespan	Adults	177 (95 ASD, 82 TD)	Both (ASD and TD)	RMET

Peters & Schulz, 2022	Theory-of-mind abilities in older patients with common mental disorders	Older adults	150	TD	RMET
Peterson & Wellman, 2019	Longitudinal Theory of Mind (ToM) Development	Children, Adolescents	107	Both (ASD, Deaf, and TD)	ToM Scale
Rahman et al., 2021	Sources of Cognitive Conflict and Their Relevance to Theory-of-Mind Proficiency	Young adults, Older adults	100 (50 young, 50 older)	TD	False Belief Task
Richardson et al., 2020	Response patterns in the developing social brain	Children, Adults	925	Both (ASD and TD)	fMRI, ToM Measures
Ringshaw et al., 2022	Theory of Mind and Moral Decision-Making in Autism	Children	76 (38 ASD, 38 TD)	Both (ASD and TD)	Distributive Justice Task, ToM
Sazhin et al., 2024	Trait reward sensitivity modulates connectivity	Young adults	54	TD	Ultimatum Game, Dictator Game, fMRI
Soto-Icaza et al., 2019	Beta oscillations precede joint attention and correlate with mentalization in typical development and autism	Children	44 (24 TD, 20 ASD)	Both (ASD and TD)	False Belief Task, Joining Attention Task, EEG
Steinmann et al., 2014	Developmental changes of neuronal networks associated with strategic social decision-making	Children, Adolescents, Young adults	45	TD	Ultimatum Game, fMRI
Taylor et al., 2013	The typical developmental trajectory of social and executive functions	Adolescents, Young adults	98	TD	Executive Function Tasks, Verbal Fluency

Xiao et al., 2019	Neural correlates of developing theory of mind competence	Children	124	TD	fMRI, ToM Measures

ASD autism spectrum disorder; TD typical development; ND neurodivergent development; DLD developmental language disorder; ADHD attention deficit and hyperactivity disorder; EEG electroencephalogram; fMRI functional magnetic resonance image

2.4. Theory of Mind Across the Lifespan: Developmental Trajectories and Neurodevelopmental Variation

From the 36 selected studies, 27 focused on ToM measures, be it on different age groups, neurodevelopmental condition and/or linked to social preferences, EFs or neuroimage measures (*Babarczy et al., 2024; Bottiroli et al., 2016; Cantio et al., 2018; Castelli et al., 2010; Castelli et al., 2014; Cavallini et al., 2013; Dufour et al., 2013; Dumontheil et al., 2010; Fischer et al., 2017; Gabriel et al., 2021; Garcia-Molina & Clemente-Estevan, 2019; Girardi et al., 2018; Grainger et al., 2021; Hughes & Ensor, 2008; Huyder et al., 2017; Jelili et al., 2022; Moor et al., 2012; Moran et al., 2011; Pagni et al., 2020; Peters & Schulz, 2022; Peterson & Wellman, 2019; Rahman et al., 2021; Richardson et al., 2020; Ringshaw et al., 2022; Taylor et al., 2013; Xiao et al., 2019*). From those 26 articles, 8 studied the difference of ToM measures in various age groups and TD and ND poulations (*Dumontheil et al., 2010; Fischer et al., 2017; Grainger et al., 2021; Jelili et al., 2022; Pagni et al., 2020; Peters & Schulz, 2022; Peterson & Wellman, 2019; Rahman et al., 2021*). Five studies explored the relationship between ToM and social preferences in children, younger adults and older adults, with TD and ND (*Castelli et al., 2010; Castelli et al., 2014; Girardi et al., 2018; Moran et al., 2011; Ringshaw et al., 2022)*. Another group of 9 articles researched the role of EFs in ToM typically and non-typically developing children, adolescents and younger adults *(Babarczy et al., 2024; Bottiroli et al., 2016; Cantio et al., 2018; Cavallini et al., 2013; Gabriel et al., 2021; Garcia-Molina & Clemente-Estevan, 2019; Hughes & Ensor, 2008; Huyder et al., 2017; Taylor et al., 2013)*. A final batch of 5 studies examined the link between ToM and brain activity (fMRI, EEG) in children, adolescents and adults, with TD and ND (*Dufour et al., 2013; Moor et al., 2012; Richardson et al., Soto-Icaza et al., 2019; 2020; Xiao et al., 2019*).

Findings converge on the view that basic ToM abilities—such as recognizing false beliefs—mature in early childhood, while complex, explicitly reflective forms continue developing into adolescence. Dumontheil et al. (2010) found that while basic perspective-taking plateaued after early adolescence, more sophisticated ToM involving deliberate perspective-shifting continued to improve, underscoring EF's role in advanced social cognition.

In childhood, ToM growth is not bound strictly to age. Peterson and Wellman (2019) demonstrated that initial ToM competence, rather than chronological age, predicted long-term improvement, challenging fixed-stage models and supporting the plasticity of social cognition. This insight is particularly relevant for intervention design in populations with delayed or atypical development.

Neurodevelopmental differences notably affect the trajectory of ToM. Children and adults with ASD consistently show differences in advanced and affective ToM (Jelili et al., 2022; Pagni et al., 2020), often moderated by verbal ability and pragmatic comprehension (Babarczy et al., 2024). However, these differences do not necessarily reflect general cognitive challenges. For example, children with ADHD or DLD performed comparably to TD peers in some ToM tasks, suggesting primary versus secondary distinctions in ToM impairment mechanisms.

Grainger et al. (2021) highlight another dimension: biological modulation of ToM. Their findings show that testosterone levels predict ToM performance in opposite directions in young vs. older men, emphasizing that age and sex hormones interactively shape social cognition.

Aging-related ToM changes are nuanced. While affective ToM remains relatively preserved, cognitive ToM declines, especially in tasks requiring abstract reasoning or mental state attribution (Fischer et al., 2017; Bottiroli et al., 2016). Peters and Schulz (2022) also linked ToM decline to mental health conditions and physical illness, suggesting that comorbidities, not aging alone, drive some social cognition alterations. Education appeared to buffer these effects, supporting cognitive reserve theories.

Rahman et al. (2021) further challenge assumptions of global decline by showing that older adults' difficulties may arise from EF-related conflict, not diminished ToM per se—underscoring the need for more sensitive measures that can distinguish between social-cognitive and executive alterations.

Collectively, these findings reinforce the hypothesis that ToM is not a unitary or static faculty, but rather a developmentally dynamic construct, shaped by interaction between biological maturation, cognitive control mechanisms, and social context. Neurodivergent populations reveal the modularity of ToM and the importance of distinguishing between core challenges and performance limitations arising from EF or language delays. Aging studies further underline the differential vulnerability of cognitive versus affective ToM, aligning with dual-process models in the literature. The studies reviewed highlight the multifaceted nature of ToM development and decline across the lifespan. From the gradual refinement of perspective-taking skills in adolescence to the emergence of age-related ToM alterations in adulthood, these findings emphasize the complex interplay between cognitive, neurobiological, and social factors in shaping social cognition. Importantly, methodological refinements in ToM assessment are crucial for accurately distinguishing between executive function alterations and genuine ToM alterations, particularly in aging and clinical populations. Future research should continue to investigate the neurobiological underpinnings of ToM across diverse populations, ensuring a comprehensive understanding of the mechanisms that drive social cognitive development and decline.

2.5. Executive Functions and Theory of Mind: Developmental Synergies and Dissociations

The following section inspects the variations in ToM across different stages of development, considering both typical and atypical populations, focusing on how pragmatic abilities, EFs, and neurocognitive factors shape ToM performance in children, adolescents, and older adults. Additionally, it highlights individual differences in cognitive and affective ToM, the role of working memory, and the influence of social and environmental factors on cognitive growth. EF plays a central role in ToM development, particularly in supporting cognitive ToM tasks that require working memory, inhibitory control, and mental flexibility. Across the reviewed studies, a consistent association emerged between EF maturity and ToM performance in both TD and ND groups.

EF abilities such as working memory, planning, and inhibition strongly predicted ToM outcomes, especially in children with ASD (Garcia-Molina & Clemente-Estevan, 2019; Huyder et al., 2017). EF-focused interventions showed potential for improving peer interaction and reducing problem behaviors (Hughes & Ensor, 2008), particularly where EF alterations preceded ToM delays. Gabriel et al. (2021) identified developmental milestones in adolescence, showing cognitive ToM advances between ages 13–16, with females outperforming males. Regression models pinpointed attention and memory skills as predictors of ToM gains, reinforcing the interdependence of cognitive domains during this period.

EF-ToM dynamics are particularly relevant in clinical contexts. Cantio et al. (2018) reported persistent ToM alterations in adolescents with ASD despite some EF improvements, suggesting distinct developmental pathways for these domains in ND populations. In older adults, EF decline is a major contributor to deteriorating ToM, particularly cognitive ToM. Bottiroli et al. (2016) and Cavallini et al. (2013) found that working memory updating mediated age-related drops in performance, while affective ToM remained stable. This differential trajectory underscores the importance of targeting EF in aging interventions to preserve social cognition.

The evidence reinforces the hypothesis that EF acts as a scaffolding mechanism for ToM, especially in complex social tasks involving belief attribution, inhibition of self-perspective, or planning behavior. These results support integrative models in developmental neuroscience, where EF provides the cognitive infrastructure enabling ToM maturation and resilience, particularly in aging or neurodivergence. Taken together, these studies offer a detailed account of ToM development and decline across the lifespan. The findings emphasize the importance of EFs in supporting cognitive ToM, particularly in aging and clinical populations, while affective ToM appears more resilient to decline. Moreover, the relationship between ToM and pragmatic abilities in ASD and other developmental disorders underscores the necessity of targeted assessments and interventions. Future research should continue exploring the factors influencing ToM variability, integrating neurobiological, cognitive, and social perspectives to refine theoretical models and improve intervention strategies.

2.6. ToM, Social Preferences, and Brain Activity: A Multilevel Account of Social Cognition

ToM enables individuals to navigate social interactions, interpret intentions, and assess fairness in various contexts. Across different developmental stages and clinical populations, variations in ToM abilities influence decision-making processes, moral reasoning, and neural responses to social stimuli. The following section explores how fairness considerations shape social preferences, the role of ToM in moral judgment, and the neural mechanisms underlying these processes.

Across ages, ToM abilities shape fairness preferences and decision-making strategies. Children initially apply rigid equality norms but gradually adopt equity-based principles as ToM and EF mature (Castelli et al., 2010; Castelli et al., 2014). In adults, fairness judgments become increasingly strategic and context-sensitive (Overgaauw et al., 2012), with older adults showing more rational economic behavior over fairness-driven rejection (Girardi et al., 2018).

In ASD populations, impaired ToM affects moral reasoning. Studies found these individuals often emphasize outcomes over intentions when evaluating harm or fairness (Moran et al., 2011; Ringshaw et al., 2022), aligning with early childhood patterns. These results support the critical role of ToM in transitioning from rule-based to intention-sensitive moral reasoning, especially in developmentally atypical trajectories.

Neuroimaging findings converge on a core “social brain” network—particularly the temporoparietal junction (TPJ), medial prefrontal cortex (mPFC), and anterior insula—which supports ToM and social decision-making. Across development, studies (Richardson et al., 2020; Xiao et al., 2019) report age-related increases in connectivity among these regions, reflecting greater neural specialization.

Notably, ASD individuals may activate similar brain regions but show less coordinated or flexible activation, suggesting processing differences rather than structural alterations (Dufour et al., 2013; Soto-Icaza et al., 2019). In adolescence, transitional changes in neural activation patterns (Gunther Moor et al., 2012) may reflect temporary ToM performance dips before adult-level performance stabilizes.

Neural data also illuminates how strategic social behavior is regulated. EEG and fMRI studies (Billeke et al., 2014; Harlé & Sanfey, 2012) show that theta oscillations and DLPFC activity are central to adapting social strategies and regulating emotional responses to unfairness. These dynamics shift with age: younger adults engage affective regions more strongly, while older adults increasingly rely on prefrontal cognitive control, indicating compensatory adaptation.

Altogether, the findings support the hypothesis that ToM operates at the intersection of cognition, emotion, and neurobiology, enabling individuals to navigate fairness, morality, and strategic social behavior. Developmentally, the transition from reactive to reflective social reasoning corresponds with increasing coordination between EF and ToM networks. Clinically, disrupted or delayed ToM affects moral understanding and fairness judgments, as seen in ASD. Neurologically, ToM relies not on isolated regions but on functional network integration, which continues to refine across the lifespan.

2.7. Developmental Trajectories of Social Preferences and Strategic Behavior

Across the lifespan, social preferences and strategic decision-making evolve in tandem with ToM, EFs, and broader neurocognitive maturation. While children tend to rely on simple fairness heuristics, such as equality, adults demonstrate more nuanced, context-sensitive social reasoning. Developmental shifts in behavior are mirrored by transitions in the underlying neural mechanisms supporting these decisions.

In early childhood, fairness behavior appears rigid and often egocentric. As cognitive abilities mature, children begin to incorporate intentionality, strategic reasoning, and perspective-taking into social decision-making. For example, around age 10, children begin to tailor offers in economic games like the MUG based on what others are likely to accept (Bueno-Guerra et al., 2016). This behavioral shift aligns with the development of second-order ToM and more advanced EF.

In adolescence and adulthood, fairness strategies become more adaptable and context-dependent. Adults more frequently adjust their offers based on asymmetrical information (Overgaauw et al., 2012), and older adults tend to show increased generosity (Bailey et al., 2013), possibly reflecting shifting social priorities. Interestingly, younger individuals show greater sensitivity to fairness violations from peers, whereas older adults emphasize emotional regulation and prosocial motives, consistent with socioemotional selectivity theory.

Sex differences and individual traits also influence these developmental trajectories. Older girls, for instance, tend to engage in more strategic fairness behavior than boys of the same age (Bueno-Guerra et al., 2016), while reward sensitivity modulates fairness responses and strategic bargaining across adulthood (Sazhin et al., 2024).

A consistent finding across studies is that distinct but interacting brain networks support fairness-related and strategic decision-making, with developmental changes in how these networks are engaged. These include emotion-related regions like the anterior insula, and cognitive control regions such as the dorsolateral prefrontal cortex (DLPFC) and temporoparietal junction (TPJ).

In childhood and early adolescence, fairness violations activate emotion-processing regions more strongly, while older individuals increasingly rely on prefrontal control areas to guide decision-making (Harlé & Sanfey, 2012; Steinmann et al., 2014). These findings suggest a developmental shift from affect-driven to cognitively regulated social evaluations, reflecting broader changes in neural maturation and strategy use.

Neuroimaging studies further highlight how brain activity tracks intentionality processing. Güroğlu et al. (2011) found that rejection of unintentional unfair offers increased with age, corresponding with growing activation in the TPJ and DLPFC. This supports the notion of a two-stage developmental model for the social brain—early maturation of norm detection (e.g., anterior insula), followed by later development of advanced ToM and strategic processing networks.

Contextual flexibility further differentiates individuals. For instance, Konovalov et al. (2021) showed that participants modulated their strategies based on whether they were playing against human-like or algorithmic opponents. This behavioral flexibility was reflected in variable TPJ engagement, reinforcing the TPJ’s role in social contingency processing.

The reviewed studies collectively illustrate that social preferences and strategic fairness behaviors develop gradually across the lifespan, in concert with ToM abilities and executive control. Early childhood is marked by rule-based reasoning and fairness rigidity, while adolescence and adulthood bring increased strategic complexity and neural sophistication. With age, social decision-making becomes less reactive and more deliberative, driven by both motivational changes (e.g., socioemotional goals in older adults) and cognitive control strategies. Importantly, this transition reflects not only behavioral shifts but also neurobiological reorganization, as individuals increasingly recruit frontoparietal and ToM-related regions to regulate social evaluations.

These findings directly support the broader research question of how ToM abilities relate to social preferences and neural function across development. While these studies often do not measure ToM explicitly, they clearly reveal that the capacity to reason about others’ intentions and beliefs underpins fairness reasoning and strategic social behavior. Developmental and neural evidence converge to suggest that effective social decision-making emerges from the interplay between affective sensitivity, cognitive flexibility, and the maturation of social brain networks. Future work should build on these findings by integrating behavioral, neuroimaging, and computational approaches to map how strategic social cognition evolves in typical and atypical trajectories, and how individual differences (e.g., reward sensitivity, cognitive control, neurodivergence) shape this evolution.

This review systematically addressed the central research question: How do ToM abilities develop across lifespan, and what is their relationship with EFs, neurodevelopment, and social preferences? The findings show that ToM development is protracted, nonlinear, and closely tied to EF—especially for cognitively demanding tasks. While affective ToM appears more resilient across age and diagnosis, cognitive ToM is sensitive to both developmental delays and cognitive decline, particularly in ASD and aging populations. Social preferences and fairness judgments evolve in tandem with ToM, reflecting increasing integration of mental state reasoning into moral and economic decisions. Critically, across all domains, ToM is shaped by both domain-general processes (EFs, working memory) and domain-specific social cognition mechanisms, with age and neurodivergence modulating this balance. This integrative, lifespan view aligns with contemporary models in social neuroscience, emphasizing dynamic interaction between cognitive control, neurodevelopmental variation, and social-cognitive experience.

2.8. DISCUSSION

This systematic review synthesized findings from 35 studies investigating ToM development across TD and ND populations, the relationship between ToM and EFs, its connection to social preferences, and the neural mechanisms underlying these cognitive processes. The results indicate a complex trajectory of ToM development across the lifespan, with early childhood and adolescence marking critical periods of growth, while aging and neurodevelopmental conditions introduce distinct patterns of decline and variability (Dumontheil et al., 2010; Peterson & Wellman, 2019). Withal, the findings reveal that while cognitive ToM tends to decline with age, affective ToM remains more stable (Fischer et al., 2017; Bottiroli et al., 2016). EFs emerge as a crucial factor influencing ToM performance, particularly in populations with developmental or cognitive challenges (Hughes & Ensor, 2008; Gabriel et al., 2021). Additionally, social decision-making and fairness considerations evolve across different life stages, reflecting an interaction between ToM, strategic reasoning, and emotional regulation (Bueno-Guerra et al., 2016; Overgaauw et al., 2012). Neuroimaging studies further highlight how ToM is supported by distinct yet overlapping brain networks that undergo developmental shifts across childhood, adolescence, and adulthood (Richardson et al., 2020; Xiao et al., 2019). The findings converge on a developmental model of ToM as a dynamic, multidimensional construct shaped by cognitive control, neurobiological maturation, and social experience (Illustration 1).

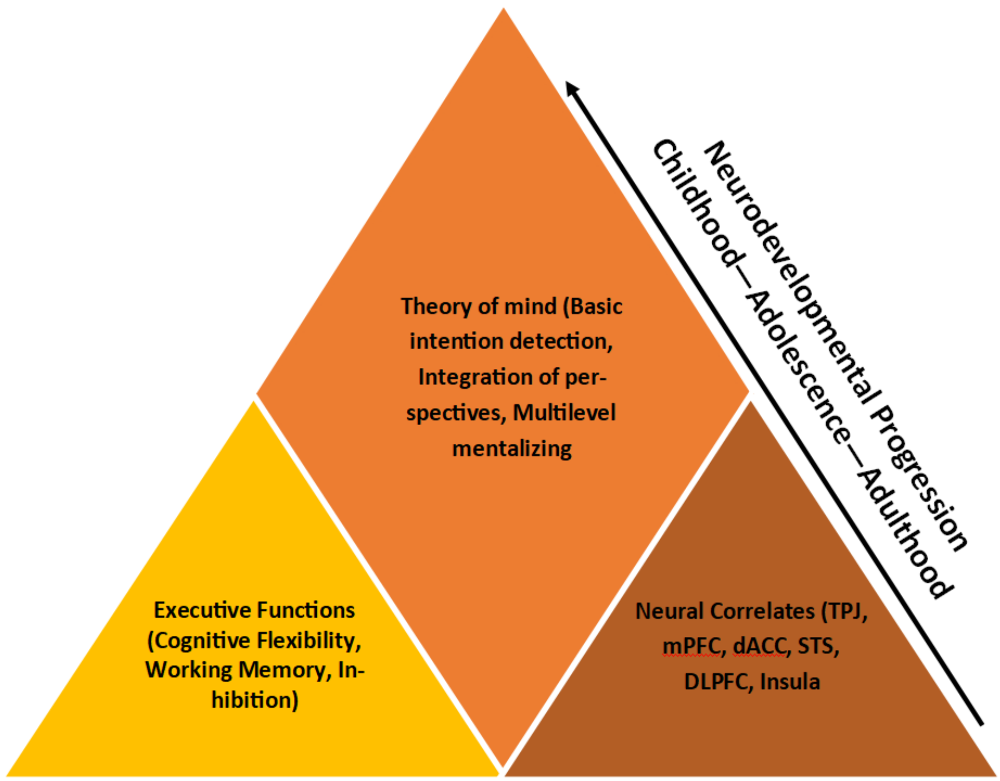


Illustration 1 - Integrative Model

Early childhood marks the emergence of first-order ToM (basic false-belief understanding), supported by language and working memory. As children mature, higher-order ToM (reasoning about others' beliefs about beliefs) develops, requiring inhibitory control and flexible perspective-taking (Dumontheil et al., 2010; Gabriel et al., 2021). This transition coincides with increased fairness considerations in decision-making, moving from rigid equality rules to more strategic, context-sensitive judgments (Castelli et al., 2010; Castelli et al., 2014).

Neural correlates include early recruitment of the anterior insula and anterior cingulate for norm violation detection, followed by maturation of the temporoparietal junction (TPJ) and dorsolateral prefrontal cortex (DLPFC) for higher-order reasoning (Güroğlu et al., 2011; Gunther Moor et al., 2012).

Adolescence and early adulthood represent a refinement stage, where ToM becomes increasingly integrated with EF and reward systems, enabling strategic cooperation, reciprocity, and fairness. During this period, neuroimaging studies show greater connectivity across the “social brain” (mPFC, TPJ, STS), reflecting heightened flexibility in evaluating intentions and outcomes (Richardson et al., 2020; Xiao et al., 2019). Decision-making shifts toward balancing fairness with self-interest, supported by the gradual maturation of control networks (Bueno-Guerra et al., 2016; Overgaauw et al., 2012).

Adulthood and aging introduce divergence between ToM components: cognitive ToM (reasoning about abstract beliefs) declines, while affective ToM (emotional understanding) remains relatively stable (Fischer et al., 2017; Cavallini et al., 2013). Older adults, though less accurate in complex cognitive ToM tasks, tend to favor prosocial and generous behaviors in economic exchanges, consistent with socioemotional selectivity theory (Bailey et al., 2013; Harlé & Sanfey, 2012). Neuroimaging indicates compensatory reliance on prefrontal regions (DLPFC, inferior parietal gyrus) to regulate fairness judgments and sustain social decision-making (Harlé & Sanfey, 2012).

Neurodivergent populations provide further insight into ToM variability. Individuals with ASD exhibit persistent challenges in both cognitive and affective ToM, particularly in moral reasoning tasks that require distinguishing intentions from outcomes (Moran et al., 2011; Ringshaw et al., 2022). These alterations are partly related to EFs difficulties but extend beyond them, suggesting domain-specific disruptions in social cognition (Rahman et al., 2021; Babarczy et al., 2024). In ADHD and DLD, EFs limitations affect pragmatic communication more than core ToM abilities (Garcia-Molina & Clemente-Estevan, 2019). Neural studies indicate that while ASD groups may recruit similar ToM-related regions, the magnitude and coordination of activity differ, pointing toward atypical processing strategies rather than global dysfunction (Dufour et al., 2013; Richardson et al., 2020).

Taken together, the reviewed evidence supports a neurodevelopmental decision-making model in which ToM matures in parallel with EF and neural networks of social cognition. This model explains age-related shifts in fairness, cooperation, and moral reasoning, and highlights the vulnerability of cognitive ToM to both neurodevelopmental and age-related decline, whereas affective ToM shows greater resilience.

Several limitations temper the conclusions of this review. First, most studies are cross-sectional, limiting insight into individual developmental trajectories. Longitudinal designs are essential to track how ToM, EF, and social decision-making co-evolve across the lifespan (Peters & Schulz, 2022). Second, methodological heterogeneity complicates comparisons: tasks such as false-belief paradigms, economic games, and faux pas tests capture different facets of ToM and may not be interchangeable. Future work should employ multi-method approaches and integrate more ecologically valid paradigms, including naturalistic and interactive tasks (Grainger et al., 2021).

Third, while evidence highlights hormonal and biological influences (e.g., testosterone effects on ToM performance), these findings are underexplored, especially in females, pointing to a need for broader neuroendocrine research (Grainger et al., 2021). Fourth, cultural influences on ToM and fairness remain insufficiently examined, despite evidence that social cognition is shaped by norms and socialization practices. Cross-cultural and cross-linguistic studies would enrich current lifespan models (Garcia-Molina & Clemente-Estevan, 2019). Finally, this review was restricted to major databases (Web of Science, PubMed, Scopus), which may have excluded psychology-specific sources such as PsycINFO. Expanding the scope of database coverage could improve the comprehensiveness of future reviews.

This work emphasizes that ToM is best understood as a lifespan construct embedded within cognitive control systems and social brain networks. Its development shapes—and is shaped by—decision-making across contexts of fairness, cooperation, and moral reasoning. The integrative model proposed here situates ToM within a neurodevelopmental framework, linking childhood emergence, adolescent refinement, adult application, and aging-related decline to corresponding neural and cognitive mechanisms.

Future research should refine this model by combining behavioral, neuroimaging, and computational approaches, with a focus on longitudinal designs, ecological validity, and cultural diversity. Such work will be crucial to clarifying the mechanisms that sustain or impair ToM across diverse populations and developmental stages, ultimately guiding targeted interventions in education, clinical practice, and social policy.

3. STUDY 2: SOCIAL PREFERENCES ACROSS DEVELOPMENT: THEORY OF MIND AND RESPONSIVENESS IN A REPEATED ULTIMATUM GAME

3.1. Introduction

Understanding human social cognition has been a central focus in developmental psychology and cognitive neuroscience. Among the most studied aspects of social cognition is Theory of Mind (ToM**),** the ability to attribute mental states, such as beliefs, intentions, and emotions, to oneself and others (Premack & Woodruff, 1978). According to Ho, Saxe, & Cushman (2022), it can also be defined as an abstract causal model of the mind that outlines how various mental states—such as perceptions, beliefs, and desires—interact to influence actions and emotions. This model serves dual purposes: it enables prediction (forecasting actions based on inferred beliefs and desires) and facilitates action planning (choosing the most suitable course of action by considering beliefs and desires). Importantly, this causal model can be applied to other's or self mental representations. ToM is crucial for everyday social interactions, as it enables individuals to predict and interpret the actions of others. However, its development is not uniform; instead, it follows a dynamic trajectory from early childhood to adulthood (Baron-Cohen, 1995). While some ToM-related skills emerge early in life, others become more refined with age and cognitive maturity.

Prior research highlights that the integration of fairness preferences and sensitivity to others develops across the lifespan. In childhood, fairness judgments often follow rigid equality rules, with children tending to reject unequal offers regardless of context (Wellman, Cross, & Watson, 2001; Happé & Frith, 2014). By adolescence, negotiation strategies become more strategic, influenced by peer relationships and sensitivity to social expectations (Blakemore & Mills, 2014). In adulthood, individuals demonstrate more flexible integration of fairness and self-interest, with social decision-making shaped by cooperative motives and prosocial behavior (Giovagnoli, 2019). Older adults often show a stronger emphasis on generosity and maintaining positive social interactions, consistent with socioemotional selectivity theory (Bailey et al., 2013). These findings underscore that social preferences and responsiveness to others evolve dynamically with age.

This study has significance across several domains. In developmental psychology, it contributes to understanding how fairness and cooperation emerge across childhood, adolescence, and adulthood. In behavioral economics, it provides insights into how fairness norms shape bargaining and cooperation. In clinical psychology, it has implications for understanding social cognition in populations with neurodevelopmental conditions such as autism spectrum disorder (ASD) and attention-deficit/hyperactivity disorder (ADHD), where difficulties with ToM and social preferences may disrupt negotiation strategies. By bridging these perspectives, the study contributes to a comprehensive account of how social preferences and sensitivity to others guide social decision-making across development, seeking to address the question: How does the integration of one’s and others’ social preferences differentially affect social decision-making throughout development? The main hypothesis posits that social preferences and responsiveness to others’ social preferences differentially influence decision-making strategies in the Ultimatum Game (UG), depending on the individual's age and level of ToM development.

To test the hypothesis, this study is guided by several general and specific objectives. Broadly, it aims to examine how individuals integrate personal and social preferences into their decision-making processes, explore the developmental trajectory of negotiation strategies from childhood to adulthood, and investigate the role of ToM and fairness perceptions in shaping social behavior. Although ToM is not measured directly in this research (e.g., through false-belief tasks), instead it is estimated indirectly through participants’ reactivity or learning from others during the UG, which functions as a proxy for ToM. In this sense, reactivity to others reflects the extent to which individuals adjust their behavior in response to social feedback, providing an indirect but meaningful measure of perspective-taking and intention tracking. More specifically, the study seeks to analyze how both cognitive and affective ToM influence decision-making in UG, assess how different age groups respond to fairness and inequity in social exchanges, and determine whether individuals adjust their strategies based on prior social interactions. Additionally, it aims to identify clusters of decision-making strategies to better understand behavioral patterns across development. By addressing these objectives, the research aspires to construct a comprehensive developmental model of social decision-making, integrating cognitive and affective components of ToM with real-world economic behaviors.

To ensure a clear and structured presentation of the research, the study is organized into key sections. The Theoretical Background provides an in-depth review of ToM development, summarizing key studies on cognitive and affective ToM across different life stages and discussing the role of EFs, social cognition, and fairness preferences in shaping decision-making. The Methodology section outlines the experimental design, including participant selection, data collection procedures, and statistical analyses, while also detailing the use of the UG to assess social decision-making and fairness perceptions across various age groups. The Results section presents the study’s findings, incorporating descriptive statistics, mixed-effects modeling, and Markov chain analyses to examine offer behavior in the UG, alongside a cluster analysis that identifies distinct behavioral patterns among participants. Finally, the Discussion interprets these findings in the context of existing theories of social cognition and ToM development, emphasizing key developmental trends in negotiation strategies and the influence of cognitive maturity and social experiences on decision-making.

Hypothesis and objectives:

Research question: How does integration between one's and others' social preferences differentially affect social decision making throughout development?

Hypothesis: Social preferences and reactivity to other's social preferences differentially affect decision making (social negotiation) throughout development.

Dependent variables: Decision making, Social decision making

Independent variables: Theory of mind (reactivity/learning from others), age, social preferences (perceived fairness/inequity in the UG game).

General Objectives

1. To examine how the integration of one's own and other's social preferences influences social decision-making across different stages of development.
2. To explore the developmental trajectory of social negotiation strategies in response to individual social preferences and the ability to react to others' preferences.

Specific Objectives

1. To analyze the impact of theory of mind (reactivity and learning from others) on social decision-making and negotiation across different age groups.
2. To assess how perceived fairness and inequity in the Ultimatum Game (UG) shape decision-making strategies in children, adolescents, and adults.
3. To investigate age-related differences in sensitivity to social preferences and their influence on social negotiation outcomes.
4. To determine whether developmental changes in social preferences predict variations in fairness-based decision-making strategies.
5. To identify interaction effects between age, theory of mind, and social preferences on social negotiation strategies.

3.2. Theoretical Background

Early Development of Social Cognition and Social Preferences

Initially, it is important to note that the developmental process of ToM and its related skills is not a homogenous one, nor is it an “all or nothing” milestone. As mentioned by Baron-Cohen (1995) some ToM proficiencies are established in the early stages of life, and others develop later as children grow and mature.

Furthermore, there is a line of studies that argue the existence of an "implicit ToM", i.e., the ability to predict another's behavior before language acquisition (use of gaze as a marker) (Southgate et al., 2007; Surian et al., 2007; Baillargeon et al., 2010). According to this research line, the "explicit ToM" requires a fair degree of verbal development in order to express the prediction of the other's behavior, which excludes the possibility of prelinguistic stages of development being a priori eliminated.

The development of social cognition is gradual and heterogeneous, progressing from early perceptual skills to more complex reasoning about others' intentions. Although not directly assessed in this study, ToM is often discussed in relation to social preferences, since both shape how children interpret fairness and cooperation. Early in life, infants display precursors to social cognition, such as emotion recognition and gaze following (Happé & Frith, 2014; Farroni et al., 2002). These skills support the ability to perceive intentions as early as three to four months of age and are critical foundations for both ToM and fairness judgments.

Research distinguishes between "implicit" ToM—observable before language acquisition through gaze and action prediction (Southgate et al., 2007; Surian et al., 2007; Baillargeon et al., 2010)—and "explicit" ToM, which requires verbal reasoning and stabilizes around 5–6 years, when children consistently succeed in false belief tasks (Wellman, Cross, & Watson, 2001; Piazza, Buresh,

& Whitney, 2020; Langley, Cirstea, Cuzzolin, & Sahakian, 2022). Relatedly, children also develop affective and cognitive components of ToM (Operto et al., 2020), which support recognition of emotions and the prediction of others' beliefs. These skills mature alongside EFs—including inhibition, working memory, and cognitive flexibility (Zelazo & Müller, 2002; Diamond, 2006, 2013; Crone & Steinbeis, 2017; Friedman & Robbins, 2022)—although the degree of independence between ToM and EF remains debated (Sai et al., 2021; Poulin-Dubois, 2020).

Environmental factors also contribute to early social cognition. Exposure to conversations about mental states and the presence of siblings enhance ToM development (Soto-Icaza & Billeke, 2017; Atzil et al., 2018; Langley et al., 2022). These environmental inputs, combined with maturing EF, provide the groundwork for the emergence of fairness judgments and social preferences.

Atypical Development and Social Cognition

Variability in social cognition is evident in atypical neurodevelopment. Conditions such as autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), oppositional defiant disorder (ODD), conduct disorder (CD), Gilles de la Tourette syndrome (GTS), obsessive-compulsive disorder (OCD), and mood disorders have all been linked to ToM and EF differences, which in turn affect social behavior (Szamburska-Lewandowska, Konowalek, & Brynska, 2021).

Children with ASD frequently show difficulties in ToM-related tasks, such as interpreting peers' emotions and initiating contact, though those with strong language skills may partially compensate (Saxe et al., 2009; Lombardo et al., 2011; Soto-Icaza et al., 2019; O'Nions et al., 2014; Senju et al., 2009). Children with ADHD also present EF alterations and ToM challenges, with performance differing according to the complexity and emotional weight of the task (Olbromska & Putko, 2014; Hutchins et al., 2016). For ODD and CD, high ToM may serve as a protective factor for perspective-taking and social prediction (Dinolfo & Malti, 2013), though aggressive tendencies and hostile attribution biases complicate this link (Burke, Loeber, & Birmaher, 2002; Kochanska et al., 2001). Research on GTS and OCD is more limited, but findings suggest differences in emotional reactivity and selective alterations in affective ToM (Capaldi & Eddy, 2015; Liu et al., 2017; Tulaci et al., 2018). Overall, these studies reinforce the importance of ToM and EF in enabling adaptive social preferences, while also showing that challenges in these domains can disrupt fairness and cooperation.

Social Preferences in Childhood

Social preferences—the motivations to act in ways that balance self-interest with others' welfare—emerge early and are critical for cooperation (Operto et al., 2020; Silk & House, 2016). Prosocial behavior can be driven by reciprocity, altruism, empathy, and inequity aversion (Decety, Steinbeis, & Cowell, 2021). By nine months, infants prefer prosocial over antisocial behaviors

(Hamlin, 2015; Ting et al., 2021), showing more positive affect when exposed to prosocial events (Steckler, 2018). Early fairness sensitivity emerges around 12 months, when infants attend to unequal resource distributions and prefer to interact with fair actors (Ziv & Sommerville, 2017; Lucca, Pospisil, & Sommerville, 2018).

During toddlerhood and preschool years, children begin to comfort others and share resources, reflecting growing empathy and fairness norms (Zahn-Waxler, Schoen, & Decety, 2018; McAuliffe et al., 2017). By age three, children strongly prefer equal splits (Huppert et al., 2019), and fairness becomes a central norm in their interactions. Neural maturation and socialization jointly support these developments, as behavioral control and advanced ToM predict sharing in distributive games across cultures (Decety & Cowell, 2018).

The UG has been widely used to measure fairness preferences. Children consistently reject unfair offers, revealing inequity aversion (Fehr, Bernhard, & Rockenbach, 2008). Castelli et al. (2014) demonstrated that children consider not only outcomes but also procedures, judging both equal splits and chance-based allocations as fair, and uniformly rejecting unfair offers. Similarly, research on children with ASD showed higher acceptance of unfair offers compared to typically developing peers, suggesting reduced integration of fairness norms (Jin et al., 2020).

Social Preferences in Adolescence

Adolescence is marked by heightened peer influence, risk-taking, and competitive motives (Blakemore & Mills, 2014; Kumar et al., 2022). Peer attachment is positively linked to ToM skills and prosocial behavior, with stronger associations in girls and younger adolescents (Białecka-Pikul et al., 2021). Conversely, lower ToM has been associated with vulnerability to peer pressure and risk behaviors, such as underage drinking (Kumar et al., 2022a, 2022b; Lannoy et al., 2020; Winters et al., 2021).

Language and communication also play a role in social-emotional functioning during adolescence, with better ToM associated with stronger empathy and social awareness (Smit, Knoors, Hermans, Verhoeven, & Vissers, 2019). Difficulties in ToM have been linked to psychiatric risk, with high-risk adolescents showing both reduced prefrontal connectivity and weaker ToM performance (Li et al., 2017; Tin et al., 2018; Thibaudeau et al., 2020; Ilzarbe et al., 2021).

In the UG, adolescents reject unfair offers but also display framing effects, indicating susceptibility to presentation biases (Marchetti et al., 2019). Their competitive tendencies and peer sensitivity align with developmental findings that fairness norms are recognized but not always prioritized over self-interest and status concerns.

Social Preferences in Adulthood

Adulthood brings increasing stability in social preferences. Adults generally make offers close to 50-50 in the UG, reflecting internalized fairness norms and strategic cooperation (Giovagnoli, 2019). While adolescents often show competitive tendencies, adults demonstrate greater consistency, with fairness guiding both acceptance and rejection behavior.

Girardi et al. (2018) found that older adults accepted more unfair offers than younger adults, suggesting greater rationality in prioritizing some reward over none. However, differences in fairness perceptions persisted across age groups, highlighting variability in negotiation strategies. Lecce et al. (2019) showed that ToM training can improve social cognition in older adults, with EF and verbal knowledge predicting plasticity. These findings suggest that while aging can affect social cognition, interventions may mitigate decline.

Across development, fairness-related social preferences evolve from early inequity aversion in childhood (Fehr et al., 2008; Castelli et al., 2014) to competitive, peer-influenced strategies in adolescence (Kumar et al., 2022; Marchetti et al., 2019), and finally to stable, fairness-oriented decision-making in adulthood (Giovagnoli, 2019; Girardi et al., 2018). While ToM and EFs are not measured directly in this study, they are indirectly approximated through reactivity to others' preferences, which serves as a proxy for perspective-taking. This framework situates our findings within existing evidence, emphasizing how social preferences and fairness norms guide negotiation strategies across the lifespan.

In summary, the transition from adolescence to adulthood represents a critical period for continued development and refinement of ToM and its impact on social preferences. As individuals enter adulthood, their social environment becomes increasingly complex, necessitating advanced ToM skills to navigate new interpersonal challenges and responsibilities. This period is marked by significant variability in ToM abilities, which are influenced by factors such as education, gender, and cognitive functions. Understanding these developmental trajectories is essential to fostering healthy social cognition and relationships throughout adulthood. The previous examination of ToM in adulthood emphasized the link between cognitive resources and social functioning, highlighting the need for targeted interventions that support ToM development and maintenance. This comprehensive approach to studying ToM across the lifespan provides valuable insights into how cognitive training programs can be designed to enhance social cognition, particularly for populations experiencing ToM alterations.

3.3. METHODOLOGY

Participants

The initial sample consisted of three groups of 30 participants each, defined by developmental stage: Children (ages 10–12), Adolescents (ages 14–16), and Adults (ages 18–20). Data collection occurred between 2015 and 2017 in Chile's Región Metropolitana, Santiago, through an open call in universities and a random selection from schools. All procedures were carried out at the Centro de Investigación en Complejidad Social (CICS) at the Universidad del Desarrollo (UDD). Participants or their legal guardians provided informed consent prior to participation.

Cognitive abilities were assessed using age-appropriate Wechsler scales: the WISC-III for the Children and Adolescents groups and the WAIS-III for the Adult group. Both instruments were administered by specialized psychologists under standardized conditions, ensuring reliable assessment of verbal and performance-based abilities. Results confirmed that all participants had cognitive abilities within the expected range for their age, with no evidence of intellectual or neurodevelopmental alterations. Gender was not considered as a variable in the study.

Measures

After the selection process, participants engaged in a repeated UG where they played against a computer-generated algorithm but were informed, they were playing against other human players. Instructions for each participant were to maximize their earnings, making offers that would benefit them but also trying to achieve acceptable offers that would minimize rejections. Each participant played 20 rounds (i.e made 20 offers) before the "computer" player was changed. After they played against 8 different "computer" players, the game was over. This was repeated for each age group (Children, Adolescents and Adults) obtaining a total of 10.560 offers: 2.880 from the Children group, 3.360 for the Adolescents group and 4.320 for the Adults group.

Data analysis

All statistical analyses were conducted using R Studio, employing a combination of descriptive statistics, mixed-effects modeling, sequential analysis, Markov chain analysis, and clustering techniques to explore age-related trends in offer behavior. The analysis aimed to characterize developmental differences in proposer strategies, assess the stability of social decision-making across repeated interactions, and identify distinct behavioral clusters among participants.

Descriptive Statistics

Initially, to examine age-related differences in offer behavior, descriptive statistics—including measures of central tendency (mean, median), dispersion (standard deviation, variance), and skewness—were computed for each age group. These analyses provided an initial assessment of variability and distributional properties, identifying patterns of generosity, competitiveness, and stability in offers.

Mixed-Effects Modeling and Sequential Analysis

To account for repeated measures and individual proposer variability, linear mixed-effects models (LMMs) were implemented. The models included random intercepts for proposers and responders to control for individual differences in decision-making strategies. Fixed effects for feedback, prior adjustments (Delta), and age group comparisons were evaluated to determine the extent to which proposers adjusted their offers based on prior decisions and social feedback.

To explore trial-by-trial adjustments, a sequential analysis incorporating lagged feedback (lag_feedback) and prior adjustments (lag_delta) was conducted. This analysis aimed to determine whether proposers systematically incorporated past experiences into future offers. Random intercepts were included to account for individual-level variability, and interaction effects between age and sequential predictors were examined to assess developmental differences in learning-based adaptation.

In all models, offer behavior and its adjustments were captured using several core parameters. Oferta refers to the offers made by proposers during each round. Delta (Δ) represents the change in offer size from one round to the next, capturing how proposers adjusted their behavior in response to previous outcomes. Lag Delta refers to the adjustment made in the preceding round, included as a predictor of subsequent offers to test whether past modifications carried forward into future decisions. Feedback denotes whether an offer was accepted (coded as 1) or rejected (coded as 0) by responders. Lag Feedback captures the acceptance or rejection outcome from the immediately prior round, providing a trial-by-trial measure of whether previous social feedback influenced current decision-making. Although Feedback is binary, plotting regression models treats it as a continuous predictor ranging from 0 to 1, which results in model outputs and visualization lines spanning that interval. This representation reflects the estimated difference in offers between rejection (0) and acceptance (1), while interpolation between the two values is a byproduct of linear modeling. RoundJ1 indexes the number of rounds played by each proposer, enabling analysis of potential learning or refinement across repeated interactions. Finally, Group distinguishes the three developmental categories—children, adolescents, and adults—allowing examination of age-related differences in social decision-making strategies.

To ensure robustness, accuracy, and generalizability of the mixed-effects modeling and sequential analysis, bootstrapping was applied. This procedure involved resampling the original dataset with replacement, creating multiple datasets to train and evaluate the models. Bootstrapped confidence intervals were computed to assess model stability and variability in parameter estimates. The following percentile-based 95% confidence intervals were obtained for each model:

- **Model 1 Intervals**: *(42.11, 45.46)*
- **Model 2 Intervals**: *(-10.928, -1.404)*
- **Model 3 Intervals**: *(42.39, 44.17)*
- **Model 4 Intervals**: *(29.94, 35.37)*

These results confirm that the models consistently capture key patterns in offer behavior while maintaining reliable performance across different data samples.

Markov Chain Analysis

To assess the stability and evolution of offer outcomes, a Markov chain model was used to examine transitions between acceptance and rejection states across repeated rounds of the game. The transition probabilities between these states were calculated to evaluate the likelihood of offer persistence and adjustment. Steady-state distributions were estimated to determine long-term equilibrium patterns in social decision-making across age groups.

Clustering Analysis

To identify distinct social decision-making strategies**,** k-means clustering was applied based on participants' initial offers, adjustments (Delta), and feedback responsiveness (acceptance rates).

3.4. RESULTS

Descriptive analysis

To characterize age-related differences in offer behavior, we first examined the distribution of offer values (Oferta) across Children, Adolescents, and Adults. Descriptive statistics—including measures of central tendency (mean, median), dispersion (standard deviation, variance), and skewness—were analyzed to assess variability and distributional properties across age groups (Table 4).

Table 4 Descriptive results

Age Group	Mean	Median	Standard Deviation	Variance	Skewness	% Between-Subjects	% Within-Subjects
Children	44.07	50.00	15.34	235.40	-0.49	21.1%	83.2%
Adolescents	43.65	50.00	13.27	176.15	-0.77	14.7%	89.9%
Adults	45.20	50.00	14.53	211.21	-0.24	26.3%	77.7%

Age-Related Trends in Offer Behavior

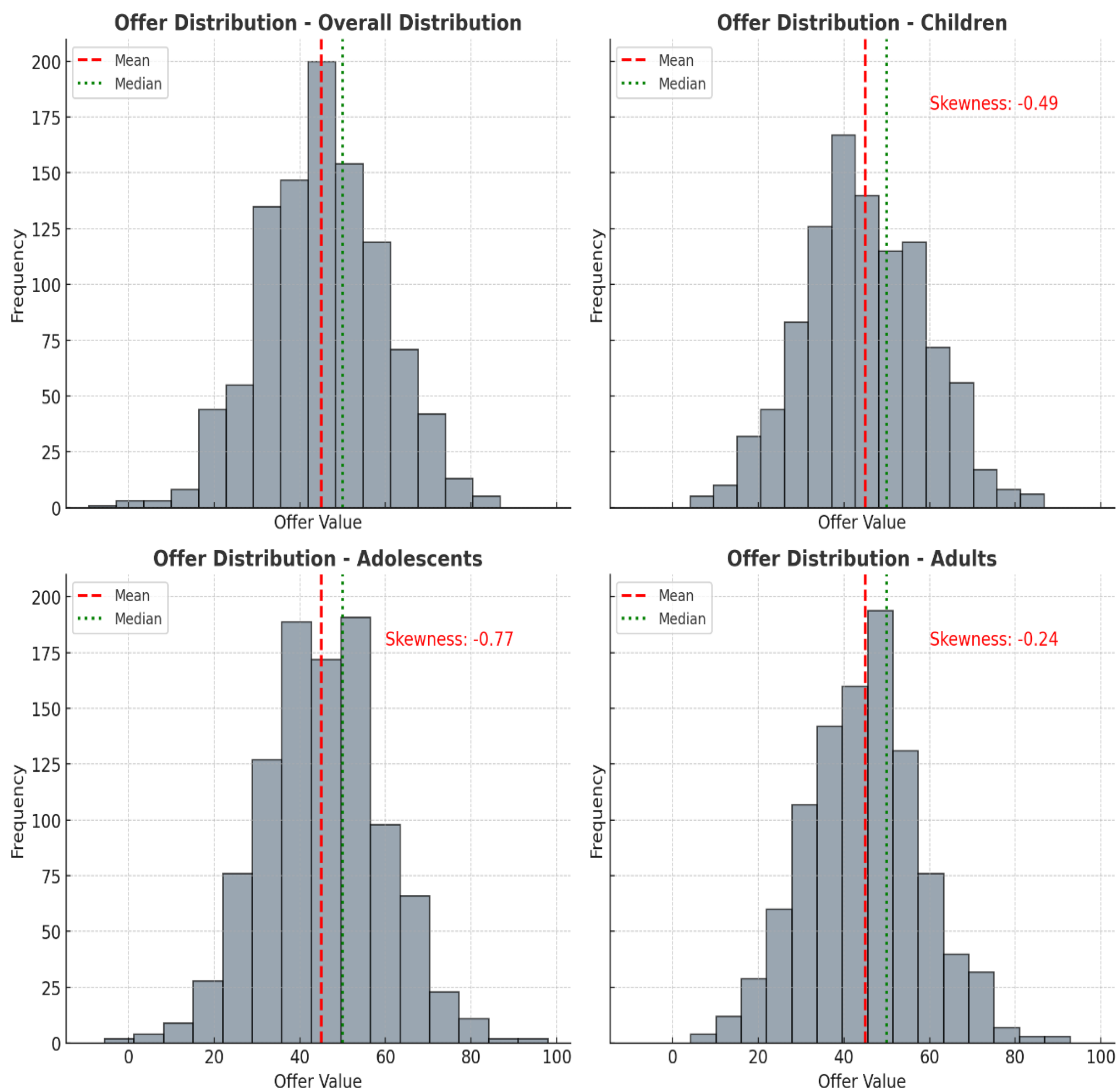
Across all groups, the mean offer ranged between 43.65 and 45.20, while the median remained consistently at 50, suggesting that most participants offered approximately half of the available amount. Adults exhibited the highest mean offers (M = 45.20), while adolescents had the lowest (M = 43.65), indicating slight developmental differences in generosity or bargaining strategies.

Variance decomposition revealed important developmental patterns in the source of variability. In Children, 83.2% of variance was explained by within-subject fluctuations across rounds, suggesting that their behavior was highly exploratory and inconsistent from trial to trial. Adolescents showed an even stronger within-subject component (89.9%), reflecting that although they behaved more similarly across individuals, they were highly inconsistent across their own rounds. In contrast, Adults showed greater stability within individuals (77.7% within-subject variance) but higher between-subject variability (26.3%), suggesting clearer and more individualized social decision-making strategies compared to Children and Adolescents.

Examining distributional shape (Figure 1), all age groups exhibited negatively skewed distributions, meaning that lower offers were more frequent than extremely high ones. Adolescents demonstrated the strongest left skew (-0.77), reinforcing their tendency toward lower offers and competitive strategies. Children’s distribution was moderately skewed (-0.49), consistent with their exploratory style. Adults had the most symmetric distribution (-0.24), reflecting more fairness-oriented and stable decision-making.

Taken together, these findings suggest that decision-making strategies become progressively more predictable and norm-driven with age. Children engage in exploratory and inconsistent negotiation strategies, adolescents display competitive tendencies with strong trial-to-trial variability, and adults prioritize fairness while showing clearer individual differences in how they negotiate.

Figure 1 Offer distributions across age groups



Histograms display the distribution of proposer offers for the overall sample and separately for children, adolescents, and adults. Red dashed lines indicate mean offers, green dotted lines indicate median offers, and skewness values are reported in each panel. Overall, offers centered around 50, though group-specific patterns emerged: children exhibited the highest variance and moderate left skew (−0.49), adolescents showed the strongest left skew (−0.77) consistent with lower offers, and adults displayed the most symmetric distribution (−0.24), reflecting greater stability in decision-making.

3.5. Mixed-Effects Modeling of Offer Adjustments

To assess whether social preferences are modulated by feedback and prior adjustments in the UG, we estimated a linear mixed-effects model (EQ1) testing Hypothesis 1: that individuals integrate feedback (acceptance/rejection) and prior adjustments (Δ) into their subsequent offers, and that this process varies by age group. This model directly addresses Specific Objective 1, by examining how reactivity to others (feedback) and past negotiation moves (Δ) shape social decision-making strategies.

The model accounted for repeated measures by including random intercepts for both proposers (J1) and responders (J2):

EQ1:

$$\text{next\_offer}_{ij} = \beta_0 + \beta_1 \cdot \text{feedback}_{ij} + \beta_2 \cdot \text{group}_i + \beta_3 \cdot (\text{feedback}_{ij} \times \text{group}_i) + \beta_4 \cdot \Delta_{ij} + \beta_5 \cdot (\Delta_{ij} \times \text{group}_i) + \beta_6 \cdot \text{RoundJ1}_{ij} + u_{J1} + u_{J2} + \varepsilon_{ij}$$

The model revealed substantial proposer-level variance (Variance = 20.74, SD = 4.55), indicating that stable individual differences drive much of the variability in offers. High residual variance (Variance = 180.85, SD = 13.45) further suggests the presence of other unmeasured factors influencing decisions, such as personality traits or idiosyncratic bargaining strategies.

Fixed-effects analyses showed that adolescents' baseline offers, without prior adjustments or feedback, were significantly above zero (β = 42.21, SE = 1.61, t = 26.15, p < 0.001). While accepted offers tended to lead to slightly higher subsequent proposals, this effect was not statistically significant (β = 0.95, SE = 0.56, t = 1.69, p = 0.09). Similarly, prior adjustments (Δ) did not predict subsequent offers (β = -0.01, SE = 0.01, t = -0.70, p = 0.49), suggesting that proposers did not systematically rely on their own recent modifications when deciding future proposals.

Contrary to expectations of age-related differences in reactivity, neither adults (β = 0.93, SE = 1.45, t = 0.64, p = 0.52) nor children (β = 0.90, SE = 1.60, t = 0.56, p = 0.57) significantly differed from adolescents in their baseline offers (Table 5). Figure 2 illustrates the mixed-effects model results, including interaction effects of feedback and group, random intercepts and slopes for proposers, explained variance (marginal vs. conditional R^2), the effect of prior adjustments on subsequent offers, and model diagnostics (Q–Q plot, residual autocorrelation).

Table 5 mixed-effects model results

Effect	Estimate (β)	SE	t-value	p-value
Intercept	42.21	1.61	26.15	< 0.001
Feedback	0.95	0.56	1.69	0.09
Delta	-0.01	0.01	-0.70	0.49
Adults (vs Adolescents)	0.93	1.45	0.64	0.52
Children (vs Adolescents)	0.90	1.60	0.56	0.57

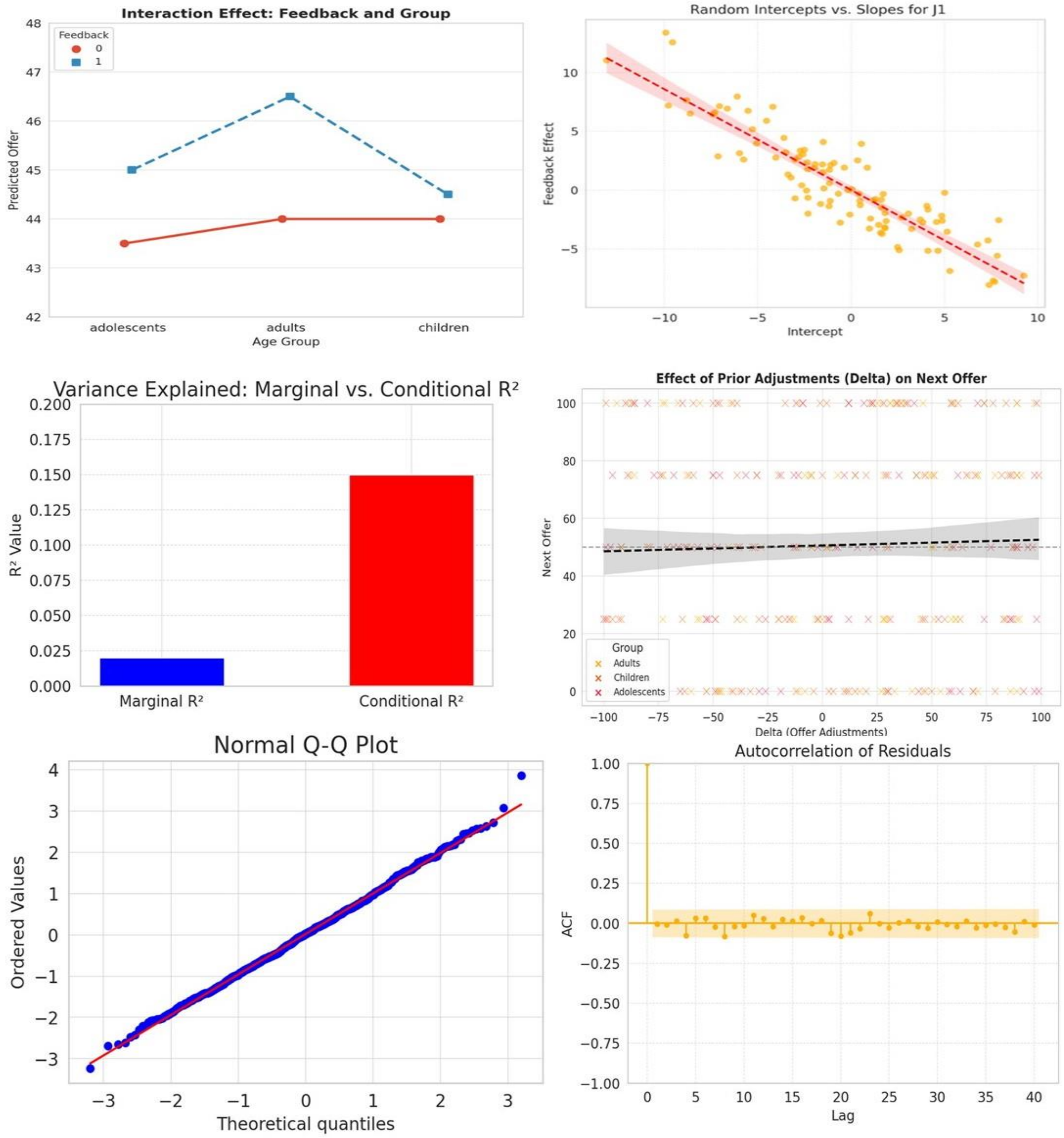
Developmental Stability in Social Decision-Making

To further test that the impact of feedback and prior adjustments on offers varies with age, we examined interaction terms between feedback × group and Δ × group. This connects to Specific Objective 3, by probing whether age moderates sensitivity to social feedback in negotiation contexts.

Results showed that feedback effects were stable across age groups (adults: $\beta = 0.86$, SE = 0.75, $t = 1.15$, $p = 0.25$; children: $\beta = -1.13$, SE = 0.83, $t = -1.36$, $p = 0.17$). Prior adjustments also did not differentially influence subsequent offers by age (adults: $\beta = 0.001$, SE = 0.02, $t = 0.06$, $p = 0.95$; children: $\beta = -0.022$, SE = 0.02, $t = -1.10$, $p = 0.27$).

Taken together, these results suggest that proposers did not systematically integrate past adjustments or feedback into their future offers, regardless of developmental stage. While fixed effects had limited explanatory power, large proposer-level variance supports the interpretation that individual differences in decision-making strategies outweigh developmental group effects. The REML criterion (80829.4) confirmed that while proposer-level variability is well modeled, fixed predictors added relatively little explanatory value.

Figure 2: Model diagnostics and effects for mixed-effects analysis of proposer offers.



Top left: Interaction plot showing predicted offers by feedback (accepted vs. rejected) across age groups, indicating consistently higher offers following acceptance. Top right: Random effects plot of intercepts vs. slopes for proposers (J1), highlighting individual variability in responsiveness to feedback. Middle left: Variance explained by marginal and conditional R^2, showing that variance is largely attributable to random effects rather than fixed predictors. Middle right: Effect of prior adjustments (Δ) on subsequent offers, indicating minimal predictive influence across groups. Bottom left: Q–Q plot of model residuals, confirming approximate normality. Bottom right: Autocorrelation function of residuals, showing no strong temporal dependence across lags.

3.6. Change in Offer Adjustments (Δ) Over Time

To evaluate whether proposers adjust their offers in response to feedback and whether this adjustment process varies by age or across repeated rounds, we estimated a linear mixed-effects model of Δ (EQ2). This analysis directly tests the hypothesis that reactivity to others' preferences (feedback/acceptance) influences subsequent negotiation moves and addresses Specific Objective 1 and 3 by examining how this reactivity interacts with age. In addition, by incorporating round progression, the model also speaks to Specific Objective 4, probing whether repeated negotiation leads to systematic refinement of fairness-based strategies.

EQ2: $\Delta_{ijk} = \beta_0 + \beta_1 \text{feedback}_i + \beta_2 \text{group}_j + \beta_3 \text{RoundJ1}_k + \beta_4 (\text{feedback} \times \text{group})_{ij} + \beta_5 (\text{feedback} \times \text{RoundJ1})_{ik} + \beta_6 (\text{group} \times \text{RoundJ1})_{jk} + \beta_7 (\text{feedback} \times \text{group} \times \text{RoundJ1})_{ijk} + u_{J1} + u_{J2} + \epsilon_{ijk}$

The model showed that accepted offers prompted significantly larger positive adjustments ($\beta = 15.24$, SE = 1.31, t = 11.61, $p < 0.001$), confirming that social feedback directly drives proposer behavior. This effect was stable across rounds and consistent across age groups.

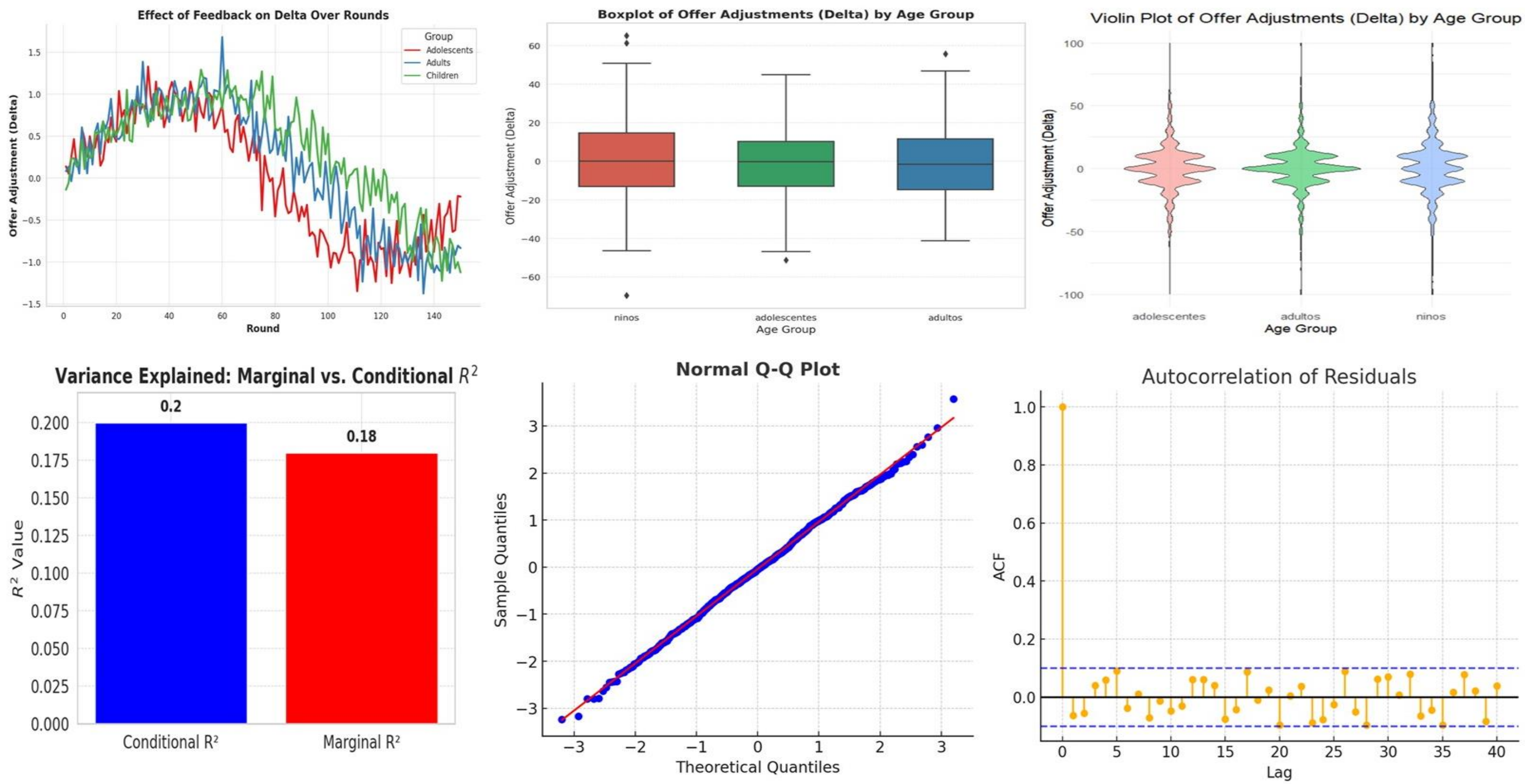
Adolescents, however, displayed a baseline tendency toward negative adjustments ($\beta = -8.29$, SE = 2.04, t = -4.06, $p < 0.001$), suggesting a more competitive or risk-taking strategy independent of feedback. By contrast, neither adults ($\beta = -1.08$, SE = 1.54, t = -0.70, p = 0.48) nor children ($\beta = -1.45$, SE = 1.66, t = -0.88, p = 0.38) significantly differed from adolescents in feedback responsiveness. Likewise, interaction effects (feedback × age) were not significant, reinforcing the finding that feedback sensitivity is developmentally stable. Round progression did not significantly predict adjustments ($\beta = -0.023$, SE = 0.021, t = -1.13, p = 0.26), nor did interactions with feedback or age, indicating that strategies did not systematically evolve over repeated negotiation trials (Table 6).

Random effects analysis revealed that substantial variance was attributable to responder-level tendencies, suggesting that proposer adjustments were partly shaped by the idiosyncratic behavior of individual responders. Figure 3 summarizes these results, showing the temporal dynamics of adjustments across rounds, the distribution of Δ across age groups (boxplot and violin plot), and model diagnostics (variance explained, Q–Q plot, residual autocorrelation). This highlights that while feedback has a robust effect on proposer adjustments, its influence is consistent across development and does not accumulate across rounds.

Table 6 Offer Adjustments (Δ) Over Time model results

Effect	Beta (Estimate)	SE (Std. Error)	t-value	p-value
Intercept	-8.29	2.04	-4.06	< 0.001
Feedback	15.24	1.31	11.61	< 0.001
Adults (vs Adolescents)	-1.08	1.54	-0.70	0.48
Children (vs Adolescents)	-1.45	1.66	-0.88	0.38
RoundJ1	-0.023	0.021	-1.13	0.26
Feedback × Adults	0.82	1.77	0.47	0.64
Feedback × Children	2.31	1.92	1.20	0.23
Feedback × RoundJ1	0.0067	0.0139	0.48	0.63
RoundJ1 × Adults	0.0166	0.0153	1.08	0.28
RoundJ1 × Children	-0.0145	0.0166	-0.87	0.39
Feedback × RoundJ1 × Adults	-0.026	0.0186	-1.40	0.16
Feedback × RoundJ1 × Children	0.019	0.0203	0.92	0.36

Figure 3: Model diagnostics and distribution of offer adjustments (Δ) across age groups.



Top left: Line plot of offer adjustments (Δ) across rounds, showing feedback-driven fluctuations over time for each age group. Top middle: Boxplot of Δ by age group, indicating central tendency, dispersion, and outliers in adjustment behavior. Top right: Violin plot of Δ by age group, visualizing the full distribution of adjustments and density of responses. Bottom left: Variance explained by marginal and conditional R^2, suggesting that both fixed and random effects contributed to model fit. Bottom middle: Q–Q plot of residuals, demonstrating approximate normality. Bottom right: Autocorrelation of residuals, indicating no strong temporal dependencies across lags.

3.7. Feedback Predicts Offers but Does Not Change Over Time

To evaluate whether feedback consistently modulates social decision-making across repeated interactions and whether this sensitivity varies by age, we estimated a linear mixed-effects model of proposer offers (EQ3). This analysis directly addresses hypothesis, which posits that social preferences and reactivity to others' behavior shape decision-making, and contributes to Specific Objectives 1, 3, and 4 by testing (a) whether feedback influences offers, (b) whether this effect accumulates across rounds, and (c) whether feedback sensitivity differs between children, adolescents, and adults.

EQ3:

$$\mathrm{Ofertaij} = \beta 0 + \beta 1 \cdot \mathrm{feedbackij} + \beta 2 \cdot \mathrm{RoundJ1ij} + \beta 3 \cdot \mathrm{groupij} + \beta 4 \cdot (\mathrm{feedback} \times \mathrm{RoundJ1})\mathrm{ij} + \beta 5 \cdot (\mathrm{feedback} \times \mathrm{group})\mathrm{ij} + \beta 6 \cdot (\mathrm{RoundJ1} \times \mathrm{group})\mathrm{ij} + \beta 7 \cdot (\mathrm{feedback} \times \mathrm{RoundJ1} \times \mathrm{group})\mathrm{ij} + \mathrm{uJ1i} + \mathrm{uJ2j} + \epsilon\mathrm{ij}$$

Feedback had a strong positive effect on proposer behavior ($\beta = 17.24$, SE = 1.17, $t = 14.80$, $p < 0.001$), with accepted offers leading to substantially higher subsequent offers compared to rejected ones. However, round progression alone did not significantly influence offers ($\beta = 0.005$, SE = 0.018, $t = 0.29$, $p = 0.77$), and the interaction between feedback and round was also non-significant ($\beta = 0.005$, SE = 0.012, $t = 0.43$, $p = 0.67$). These results indicate that feedback consistently shapes proposer behavior, but its effect does not accumulate over time.

Developmental Differences in Feedback Sensitivity and Strategy Refinement

Age differences emerged in baseline offers and in strategy refinement across rounds. Adults made slightly lower baseline offers than adolescents ($\beta = -3.07$, $SE = 1.56$, $t = -1.97$, $p = 0.05$), while children did not significantly differ from adolescents ($\beta = 0.41$, $SE = 1.69$, $t = 0.24$, $p = 0.81$). Importantly, adults adjusted their offers more over repeated rounds ($\beta = 0.041$, $SE = 0.013$, $t = 3.16$, $p = 0.002$), suggesting greater refinement of negotiation strategies with experience.

By contrast, sensitivity to feedback itself remained stable across age groups, as interactions between feedback, round, and age were non-significant (adults: $\beta = -0.029$, $SE = 0.016$, $t = -1.83$, $p = 0.07$; children: $\beta = 0.023$, $SE = 0.018$, $t = 1.29$, $p = 0.20$).

An ANOVA confirmed a significant main effect of age on mean offers ($F(2, 10555) = 12.15$, $p < 0.001$) (Table 7). Post-hoc Tukey's HSD tests (Table 8) revealed that adults offered significantly more than adolescents ($p = 0.0146$) and children ($p = 0.0398$), while children and adolescents did not differ significantly ($p = 0.9946$). Figure 4 visualizes these findings by displaying the trajectory of offers across rounds by age group, as well as group differences in mean offers confirmed by Tukey's HSD tests.

Table 7 ANOVA results

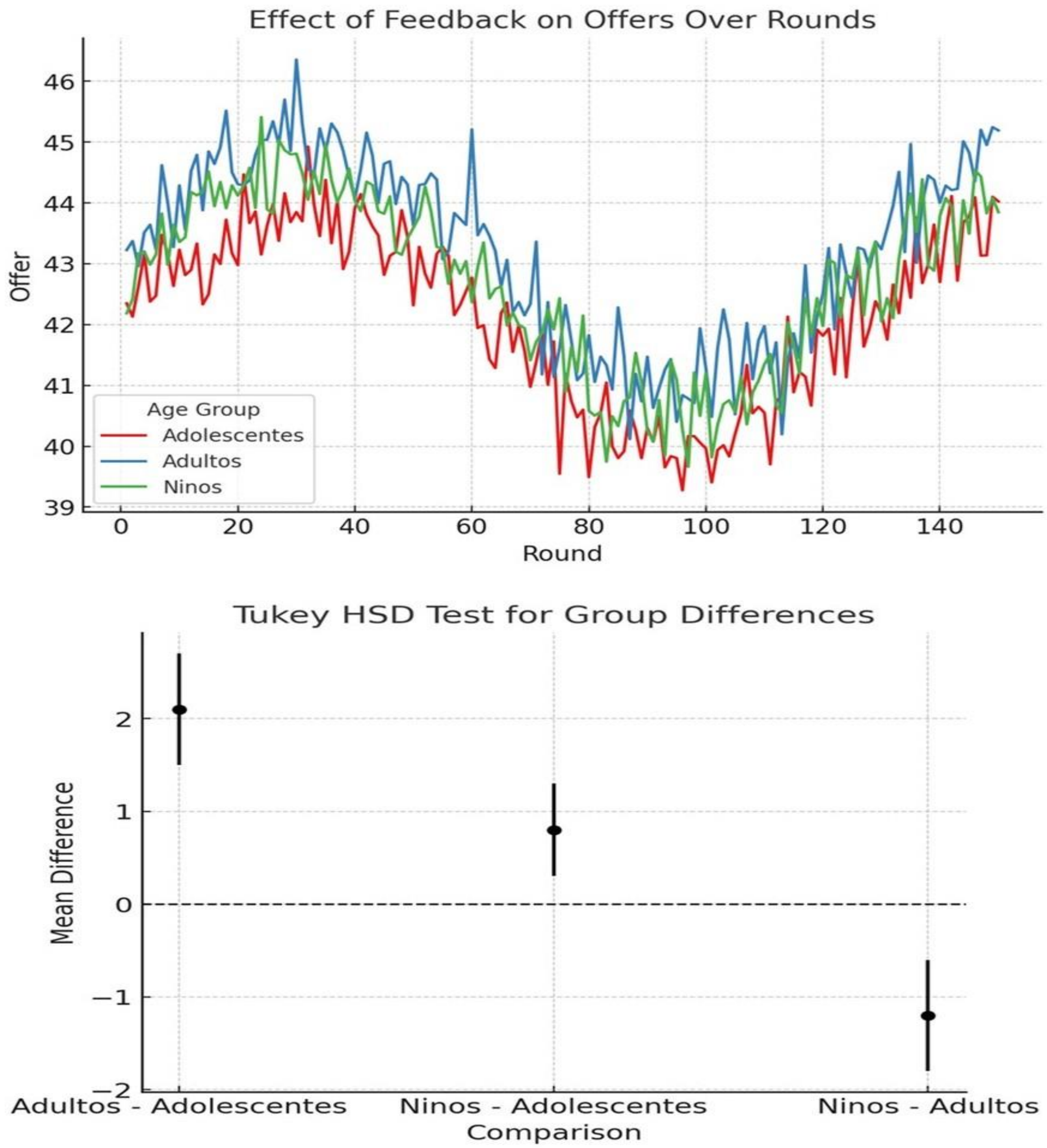
Source	Df	Sum Sq	Mean Sq	F value
Group	2	5018	2508.9	12.15
Residuals	10555	2180161	206.6	

Table 8 Tukey's HSD tests

Comparison	Difference (diff)	95% CI	Adjusted p-value
Adults vs. Adolescents	1.30	[0.21, 2.39]	0.0146
Children vs. Adolescents	1.25	[0.05, 2.45]	0.0398
Children vs. Adults	-0.05	[-1.19, 1.09]	0.9946

These findings confirm that feedback is a stable determinant of proposer behavior across development, but its effect does not strengthen or weaken over repeated interactions. Adults, however, demonstrated greater strategic refinement across rounds, adjusting their offers more consistently than younger participants. Age-related differences in mean offer generosity further suggest that fairness and cooperative motivations increase later in adolescence and persist into adulthood. Collectively, these results support the hypothesis that while all age groups rely on feedback, the broader trajectory of social decision-making becomes increasingly strategic and stable with development.

Figure 4 Developmental differences in offers across rounds and post-hoc group comparisons.



Top: Line plot of proposer offers across repeated rounds, showing the effect of feedback on offer trajectories for children, adolescents, and adults. While overall patterns were similar, adults tended to make slightly higher offers across rounds. Bottom: Tukey HSD post-hoc test results comparing mean offers between age groups. Adults offered significantly more than adolescents, whereas differences between children and adolescents or between children and adults were smaller and less consistent.

3.8. Sequential Analysis of Offers

To evaluate whether short-term learning from prior interactions influences proposer decision-making, we estimated a linear mixed-effects model including lagged predictors of feedback (lag_feedback) and adjustments (lag_delta) (EQ4). This analysis addresses Specific Objectives 1, 2, and 3 by examining (a) whether proposers integrate feedback and adjustments from previous rounds, (b) whether these sequential effects vary by age, and (c) whether age moderates the reliance on prior information in shaping offers.

EQ4: $$\text{Oferta}_{ijk} = \beta_0 + \beta_1 \text{lag\_feedback}_i + \beta_2 \text{group}_j + \beta_3 \text{lag\_delta}_k + \beta_4 (\text{lag\_feedback} \times \text{group})_{ij} + \beta_5 (\text{lag\_delta} \times \text{group})_{jk} + u_{J1} + u_{J2} + \epsilon_{ijk}$$

Fixed effects estimates revealed that adolescents' baseline offers, in the absence of prior feedback or adjustments, were significantly positive ($\beta = 43.22$, $SE = 1.24$, $t = 34.87$, $p < 0.001$). However, lagged predictors showed little influence on current behavior. Prior feedback from accepted offers had only a small, non-significant effect on subsequent offers ($\beta = 0.68$, $SE = 0.57$, $t = 1.20$, $p = 0.23$), and prior adjustments (lag_delta) were similarly unrelated to new offers ($\beta = -0.008$, $SE = 0.015$, $t = -0.53$, $p = 0.60$). This suggests that proposers did not consistently draw on their immediate past experiences when formulating subsequent offers.

Developmental Comparisons in Sequential Decision-Making

Age comparisons further confirmed limited reliance on prior information across development. Adults ($\beta = 1.25$, SE = 1.48, $t = 0.84$, $p = 0.40$) and children ($\beta = 1.36$, SE = 1.63, $t = 0.84$, $p = 0.40$) did not significantly differ from adolescents in baseline offers. Interaction terms revealed no significant age-related moderation of lagged predictors: adults did not differ from adolescents in responsiveness to prior feedback ($\beta = 0.53$, SE = 0.76, $t = 0.70$, $p = 0.49$), and children showed only a marginal, non-significant tendency toward reduced reliance ($\beta = -1.32$, SE = 0.84, $t = -1.57$, $p = 0.12$). Likewise, lagged adjustments had no differential effects by age (adults: $\beta = 0.005$, SE = 0.019, $t = 0.24$, $p = 0.81$; children: $\beta = -0.018$, SE = 0.021, $t = -0.88$, $p = 0.38$).

As shown in Table 9, these findings suggest that reliance on sequential cues (feedback or prior adjustments) is minimal and does not vary substantially with age. Instead, proposer behavior appears to be shaped more by stable individual differences than by short-term reinforcement learning. Figure 5 illustrates these findings by showing (a) the minimal predictive effect of lagged feedback and adjustments across age groups, (b) the distribution of offers by group, and (c) the distribution of proposer-level random intercepts, underscoring the role of stable individual differences in driving decision-making. Model diagnostics (Figure 6) confirmed adequate model fit. The explained variance was modest, with conditional R2=0.20R^2 = 0.20R2=0.20 and marginal R2=0.18R^2

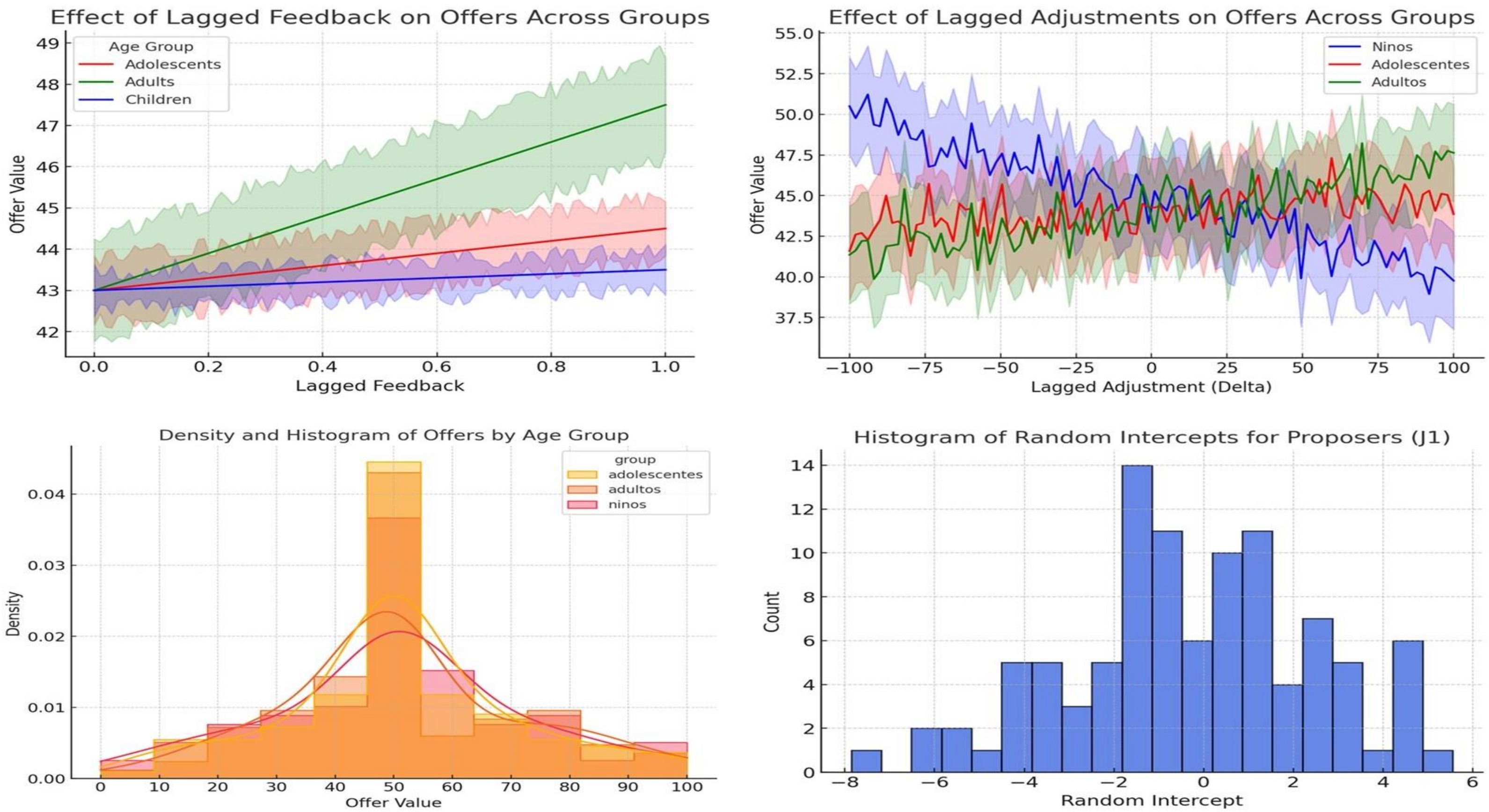
= 0.18R2=0.18, indicating that most variance stemmed from random intercepts rather than fixed effects. The Q-Q plot showed that residuals followed an approximately normal distribution, while the autocorrelation function revealed no systematic temporal dependencies across rounds. Together, these diagnostics support the robustness of the model while underscoring the limited predictive contribution of sequential predictors.

Table 9 Lagged feedback model results

Effect	Beta (Estimate)	SE (Std. Error)	t-value	p-value
Intercept	43.22	1.24	34.87	< 0.001
Lagged Feedback	0.68	0.57	1.20	0.23
Adults (vs Adolescents)	1.25	1.48	0.84	0.40
Children (vs Adolescents)	1.36	1.63	0.84	0.40
Lagged Delta	-0.008	0.015	-0.53	0.60
Lagged Feedback × Adults	0.53	0.76	0.70	0.49
Lagged Feedback × Children	-1.32	0.84	-1.57	0.12
Lagged Delta × Adults	0.005	0.019	0.24	0.81
Lagged Delta × Children	-0.018	0.021	-0.88	0.38

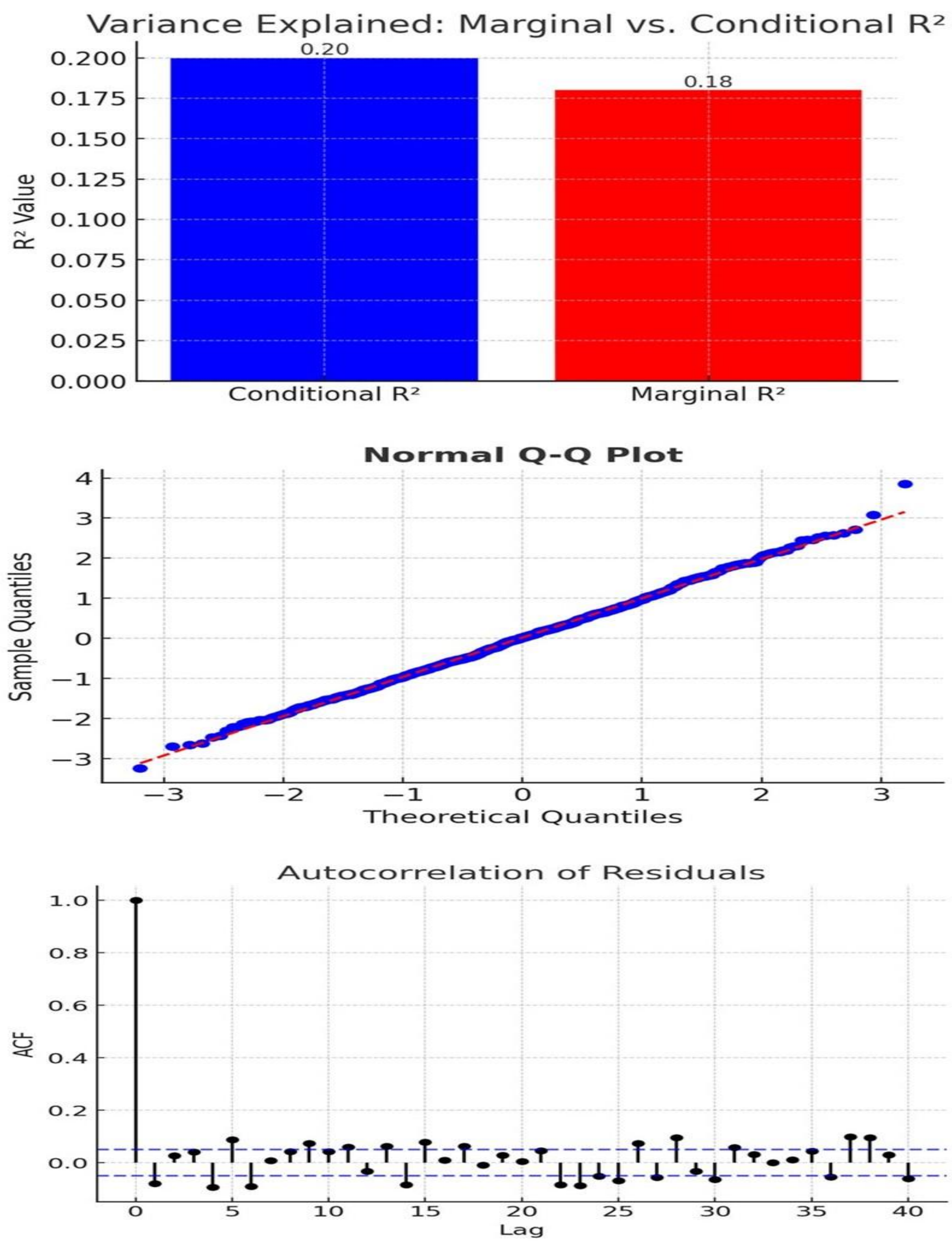
This analysis demonstrates that short-term sequential learning effects play a limited role in social decision-making. Across all age groups, proposers rarely relied on prior adjustments or feedback when making new offers. The absence of age-related differences further suggests that developmental changes in negotiation strategies are not driven by short-term reinforcement processes but rather by stable fairness preferences and individual decision-making styles. Although random effects captured meaningful proposer-level variability, fixed effects explained little variance, underscoring the dominant role of stable individual tendencies in driving bargaining behavior

Figure 5: Sequential predictors and variability in proposer offers across age groups.



Top left: Effect of lagged feedback on offers, showing that adults exhibited stronger positive adjustments following prior feedback compared to adolescents and children. Top right: Effect of lagged adjustments (Δ) on offers, with no systematic influence across groups, indicating limited reliance on prior modifications when making new proposals. Bottom left: Density and histogram of offers by age group, illustrating overlapping distributions with adults tending toward slightly higher offers. Bottom right: Histogram of random intercepts for proposers (J1), capturing individual-level variability in baseline offer tendencies.

Figure 6: Model fit diagnostics for sequential analysis.



Top: Variance explained by the model, showing both conditional R2R^2R2 (0.20), reflecting fixed and random effects combined, and marginal R2R^2R2 (0.18), reflecting only fixed effects. Middle: Normal Q–Q plot of residuals, indicating that residuals closely follow the expected normal distribution with minor deviations at the tails. Bottom: Autocorrelation function (ACF) plot of residuals, showing no substantial serial correlation across lags, supporting the independence assumption of the model.

3.9. Markov Chain Analysis of Feedback Dynamics

To investigate whether patterns of acceptance and rejection stabilize over repeated interactions, we applied a Markov chain model of proposer–responder dynamics in the UG. This analysis addresses the hypothesis by examining whether reactivity to feedback predicts long-term behavioral stability in social negotiation. It is particularly relevant to Specific Objectives 2, 3, and 5, as it captures how social preferences (acceptance vs. rejection outcomes) evolve across development and whether age moderates stability in cooperative strategies.

The transition probabilities across age groups are visualized in Figure 7, which shows that rejection outcomes were relatively unstable, with a higher probability of shifting to acceptance in the next round (0→1), while acceptance outcomes (1→1) were comparatively stable. Consistent with this, the aggregate transition matrix (Table 10) revealed that rejected offers had a 56.9% probability of becoming accepted in the subsequent round, while accepted offers persisted with 71.4% likelihood. These findings indicate that social feedback effectively guides proposers toward stable strategies over time.

Table 10 MC Transition probabilities

Current State	Rejection → Rejection (0→0)	Rejection → Acceptance (0→1)	Acceptance → Rejection (1→0)	Acceptance→ Acceptance (1→1)
All Participants	43.0%	56.9%	28.6%	71.4%

Two key patterns emerge:

1. **Rejection is unstable** – Offers resulting in **rejection** have a 56.9% probability of transitioning to acceptance in the next round, suggesting that proposers adjust their strategies to improve outcomes.
2. **Acceptance is stable** – Accepted offers tend to persist (71.4%), reinforcing the idea that social feedback guides proposers toward more stable, acceptable offers.

These findings indicate that acceptance becomes the dominant state over time, with proposers adapting their offers to sustain positive outcomes.

Long-Term Equilibrium: Steady-State Distribution

To assess long-term trends, we calculated the steady-state probabilities (Table 11), representing the expected distribution of outcomes over repeated interactions:

Table 11 Steady State probabilites

State	Probability
Rejection (0)	33.4%
Acceptance (1)	66.6%

This equilibrium confirms that, in the long run, acceptance is the more frequent outcome, aligning with transition patterns favoring shifts from rejection to acceptance.

Developmental Trends in Feedback Dynamics

Exploring age-related differences, we examined transition probabilities (Table 12) across children, adolescents and adults.

Table 12 Transition probabilities

Current State	Children (0→0 / 0→1)	Adolescents (0→0 / 0→1)	Adults (0→0 / 0→1)
Rejection (0)	39.7% / 60.3%	43.6% / 56.4%	45.3% / 54.7%
Acceptance (1)	31.9% / 68.1%	30.7% / 69.3%	24.9% / 75.1%

Three key developmental trends emerge:

1. Children are most responsive to rejection – They are most likely to transition from rejection to acceptance (60.3%), indicating high sensitivity

to feedback. However, they also struggle to maintain acceptance, with the highest probability of reverting to rejection (31.9%).

2. Adults show the most stability – They are least likely to shift from acceptance to rejection (24.9%), reinforcing greater consistency in social decision-making.
3. Adolescents are intermediate – Their behavior bridges the gap between children's exploratory tendencies and adults' stable negotiation strategies.

Behavioral Stability Across Development

To determine whether these differences were statistically meaningful, we conducted Wilcoxon signed-rank tests:

- **Rejection → Acceptance (0→1):** No significant difference between children and adolescents ($V = 3$, $p = 0.5$), indicating similar tendencies to recover from rejection.
- **Acceptance → Rejection (1→0):** No significant difference between adolescents and adults ($V = 0$, $p = 0.5$), suggesting that decision stability solidifies in late adolescence.

These results suggest that while children show greater variability, fundamental transition patterns remain stable across development.

Long-Term Stability: Age-Related Steady-State Distributions

Steady-state analyses across groups (Table 13; Figure 8) confirmed that adults maintain acceptance most consistently (68.7%), followed by children (65.4%) and adolescents (64.8%).

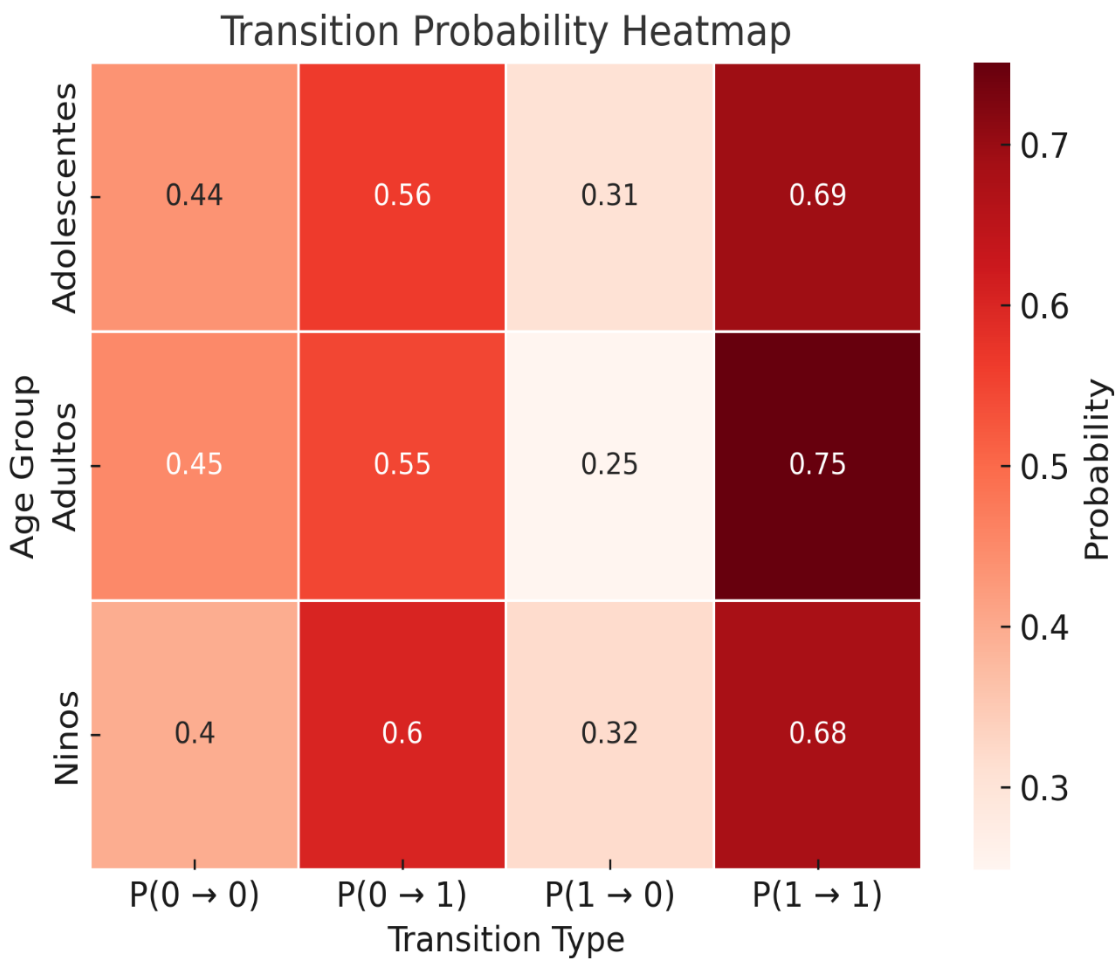
Table 13 Steady-state analyses across groups

Age Group	Rejection (State 0)	Acceptance (State 1)
Children	34.6%	65.4%
Adolescents	35.2%	64.8%
Adults	31.3%	68.7%

These findings reveal a progressive shift toward stability, with adults maintaining acceptance more consistently than children. A clear developmental trajectory emerges, with children displaying the greatest variability, frequently shifting between rejection and acceptance, indicative of exploratory behavior. Adolescents show increasing stability, maintaining accepted offers more consistently than children, while adults demonstrate the highest level of stability, reinforcing their ability to sustain cooperative behaviors. These findings are based on previous analyses, where the Sequential Analysis suggested minimal trial-to-trial learning effects, indicating limited short-term reinforcement learning.

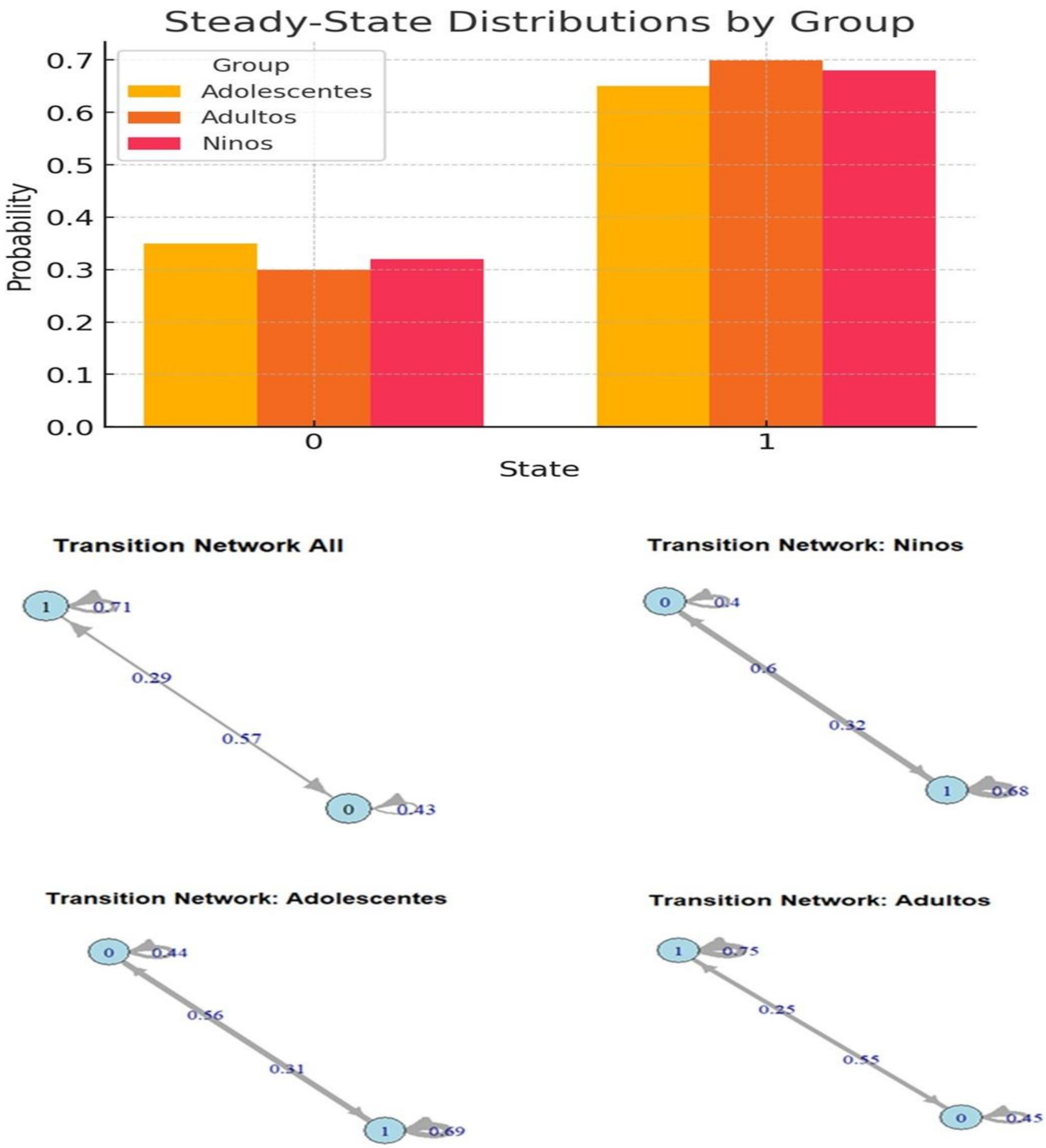
Meanwhile, the Markov Chain Analysis reveals that although individual proposers may not rely heavily on recent feedback for immediate adjustments, broader trends in acceptance stability emerge over time. The observed stability in adults further supports the idea that mature proposers develop more consistent decision-making strategies, reinforcing long-term patterns of cooperative behavior. Children are highly reactive to feedback but struggle to maintain stability, while adults exhibit the most consistent decision-making. These findings suggest that strategic consistency and reduced feedback reactivity develop with age, reinforcing the idea that social negotiation matures over time, ultimately favoring stable, cooperative exchanges.

Figure 7: Transition probability heatmap by age group.



Heatmap depicting transition probabilities between rejection (0) and acceptance (1) states in the Ultimatum Game. Across age groups, rejection is less stable than acceptance, with higher probabilities of transitioning from rejection to acceptance (P(0→1)) than remaining in rejection (P(0→0)). Adults exhibit the highest stability in maintaining accepted offers (P(1→1) = 0.75) and the lowest likelihood of reverting to rejection (P(1→0) = 0.25), while children show greater variability, with both higher responsiveness to rejection (P(0→1) = 0.60) and reduced stability in maintaining acceptance (P(1→0) = 0.32). Adolescents occupy an intermediate position, balancing responsiveness and stability.

Figure 8: Steady-state distributions and transition networks across age groups.



Top panel: Steady-state probabilities derived from Markov chain analysis, showing that acceptance (State 1) dominates across all groups, with adults exhibiting the highest long-term probability of maintaining acceptance (0.69).

Bottom panels: Transition network diagrams display state dynamics for all participants (left) and separately by age group (right panels). Transition probabilities indicate that children are most reactive to rejection (P(0→1) = 0.60) but less stable in maintaining acceptance (P(1→0) = 0.32), adolescents occupy an intermediate position (P(0→1) = 0.56; P(1→0) = 0.31), and adults show the greatest stability, with the lowest probability of returning to rejection (P(1→0) = 0.25) and the strongest persistence in acceptance (P(1→1) = 0.75).

3.10. Clustering Analysis of Social Decision-Making Strategies

To further address the hypothesis and Specific Objectives 2, 3, and 5, we conducted a clustering analysis to capture heterogeneity in proposer behavior. While the mixed-effects and Markov models identified average patterns and group-level trajectories, the clustering analysis highlights whether participants can be meaningfully grouped into distinct negotiation strategies based on their offer size (Oferta), adjustments (Delta), and feedback acceptance rates. This allows us to examine whether developmental stages are associated with specific strategic profiles in social negotiation.

The elbow method (Figure 9, bottom left) indicated that k = 3 clusters was optimal. Visualizations of 2D (Delta vs. Offer) and 3D clustering (Delta, Offer, Feedback; Figure 9, top panels) revealed three well-separated clusters. Cluster centroids (Figure 10, top left; Table 14) confirm distinct proposer strategies:

Table 14 Cluster analysis

Cluster	Delta (Adjustment)	Oferta (Offer Size)	Feedback (Acceptance Rate)	Behavioral Description
1 (Cooperative)	16.75	53.05	0.85	High offers, positive adjustments, and high acceptance rates.
2 (Competitive)	-29.93	17.98	0.11	Low offers, negative adjustments, and low acceptance rates.
3 (Stable)	-4.38	43.76	0.65	Moderate offers, small negative adjustments, and moderate acceptance rates.

These clusters illustrate three distinct approaches to social negotiation:

- **Cluster 1 (Cooperative)**: Participants in this group made the highest offers (M = 53.05) and exhibited strong prosocial tendencies, with large positive adjustments (M = 16.75) and high acceptance rates (85%). This strategy suggests a preference for maintaining cooperative interactions by ensuring positive feedback from responders.
- **Cluster 2 (Competitive)**: Comprising the smallest proportion of participants, this group exhibited self-serving behavior, making the lowest offers (M = 17.98), significantly reducing their offers after rejection (M = -29.93), and experiencing low acceptance rates (11%). These patterns indicate a competitive or risk-taking strategy, likely provoking frequent rejections.
- **Cluster 3 (Stable)**: The most prevalent group, these participants adopted a balanced approach with moderate offers (M = 43.76), minimal adjustments (M = -4.38), and intermediate acceptance rates (65%). This strategy suggests an equilibrium between self-interest and social cooperation.

Cluster Prevalence and Strategic Preferences

The distribution of participants (Table 15) across clusters underscores a preference for moderate or cooperative strategies:

Table 15 Cluster distribution

Cluster	Size (N)	Proportion (%)
1 (Cooperative)	1,815	28.5%
2 (Competitive)	605	9.5%
3 (Stable)	2,858	44.7%

- **Cluster 1 (Cooperative Behavior)** accounted for 28.5% of participants, reflecting a substantial subset of individuals who prioritize fairness and prosocial strategies.
- **Cluster 2 (Competitive Behavior**) was the smallest group, with only 9.5% of participants displaying aggressive self-interest at the cost of high rejection rates.
- Cluster 3 (Stable Behavior) was the most common, encompassing nearly half of all participants (44.7%), suggesting that most individuals gravitate toward moderation in social negotiations.

Results align with prior Markov chain analyses, which demonstrated that acceptance states are more stable than rejection states, reinforcing the idea that most proposers favor strategies that maximize acceptance and stability. The presence of a minority competitive group is consistent with the previous sequential analysis, which found that prior offer adjustments (Delta) did not significantly influence subsequent decisions, indicating that most participants do not continuously adjust based on past experiences.

Cluster Variability and Separation

Analysis of within-cluster variance (Table 16) revealed important differences in behavioral consistency:

Table 16 Within-Cluster variance

Cluster	Within-Cluster Variance (SS)
1 (Cooperative)	509,706
2 (Competitive)	277,196
3 (Stable)	321,879

- **Cluster 1 (Cooperative)** had the highest variance, indicating greater individual differences in how participants applied prosocial strategies.
- **Cluster 2 (Competitive)** exhibited the smallest within-cluster variance, suggesting that these participants follow a highly consistent risk-taking or self-serving strategy with little variation.
- **Cluster 3 (Stable)** maintained moderate variance, reflecting its role as the middle ground between cooperation and self-interest.

The between-cluster variance (1,664,664) exceeded the total within-cluster variance (1,108,780), confirming that the clusters were well-separated, with distinct behavioral profiles.

Cluster Prevalence and Age Group Distribution

The distribution of participants across clusters (Table 17) highlights age-related patterns in strategic decision-making:

Table 17 Cluster Prevalence and Age Group Distribution

Cluster	Adolescents (Count)	Adults (Count)	Children (Count)	Total Participants
1 (Cooperative)	559	672	584	1,815
2 (Competitive)	180	238	187	605
3 (Stable)	941	1,249	668	2,858

- **Cluster 1 (Cooperative Behavior)** showed relatively balanced representation, suggesting that cooperative strategies are not strongly dependent on age.
- **Cluster 2 (Competitive Behavior)** was the smallest cluster, with adolescents displaying the most extreme competitive tendencies, consistent with prior findings on risk-taking and social negotiation in adolescence.
- **Cluster 3 (Stable Behavior)** was the largest group across all ages, with adults comprising the majority (1,249 participants), reinforcing the increasing preference for stable, moderate behavior with age.

Age-Related Proportional Comparisons in Social Decision-Making Strategies

To further explore developmental trends in proposer behavior (Table 18), we analyzed the proportional distribution of clusters across age groups. The following table summarizes the percentage of participants in each cluster by age group:

Table 18 Proportional distribution of clusters across age groups

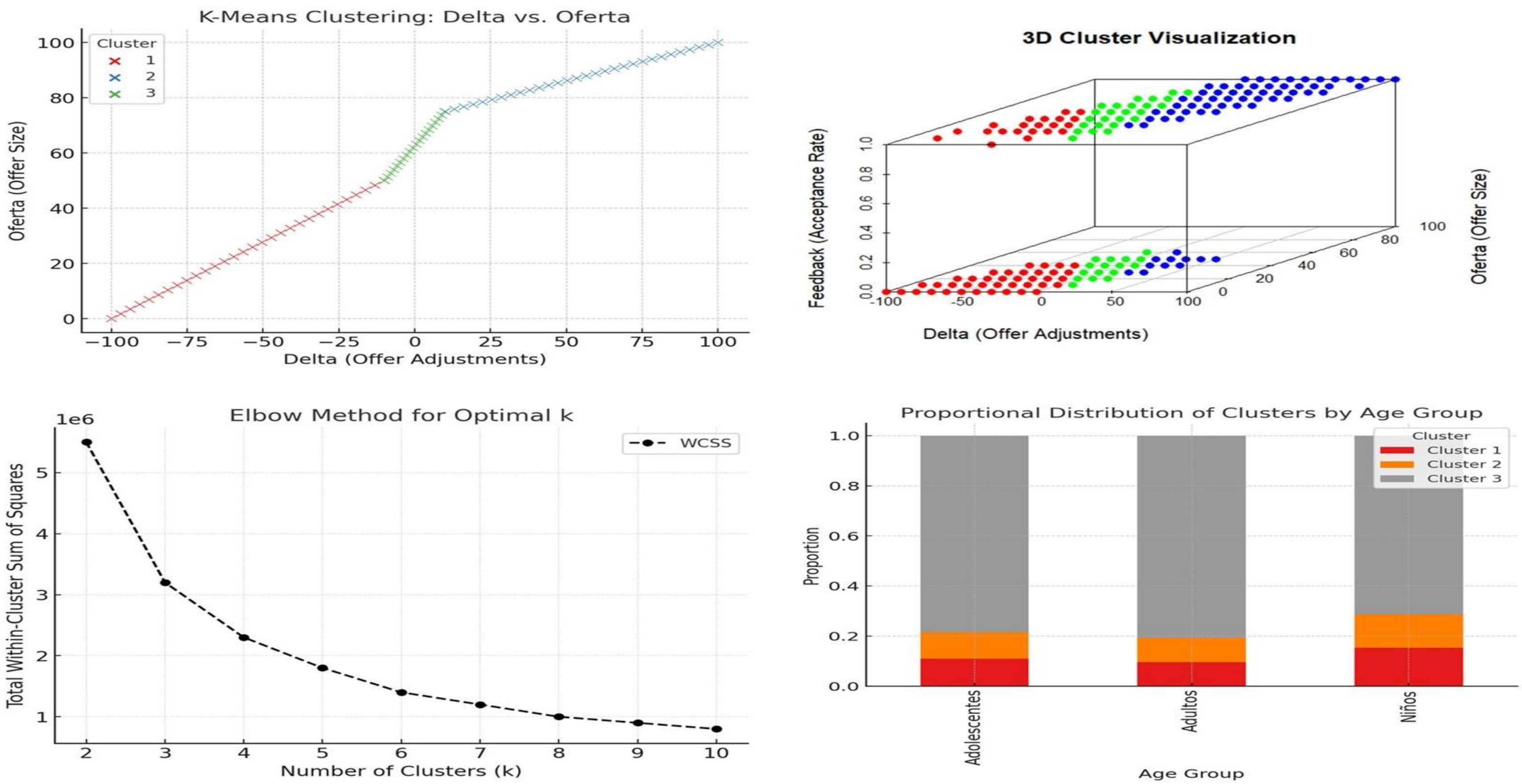
Age Group	Cluster 1 (Cooperative: High Offers)	Cluster 2 (Competitive: Low Offers)	Cluster 3 (Stable: Moderate Offers)	Total Participants
Adolescents	10.9%	10.7%	78.4%	3,360
Adults	9.6%	9.7%	80.7%	4,318
Children	15.3%	13.4%	71.3%	2,879

Figures 9–10 (bottom right and remaining panels) visualize cluster distribution by age group. These proportional differences across age groups highlight key developmental trends in social negotiation strategies. Adults and adolescents overwhelmingly exhibit stable behavior, with 80.7% of adults and 78.4% of adolescents falling into Cluster 3 (Stable Behavior), reinforcing their preference for moderate offers and minimal adjustments. This aligns with previous Markov chain analyses, which showed greater stability in maintaining accepted offers among older participants. In contrast, children display greater variability in decision-making, as they are significantly more likely than adults and adolescents

to belong to either Cluster 1 (Cooperative, High Offers; 15.3%) or Cluster 2 (Competitive, Low Offers; 13.4%). This suggests that children's decision-making is less stable, with a broader range of social strategies, consistent with their higher frequency of transitions between acceptance and rejection states.

These clustering results align with earlier Markov analyses, where acceptance was found to be more stable than rejection, reinforcing the dominance of Stable and Cooperative strategies. They also complement the sequential learning model, which showed minimal trial-to-trial reliance on feedback—suggesting that while immediate adjustments are inconsistent, participants gravitate toward broader stable or cooperative strategies across development. Together, Figures 9 and 10 demonstrate that while children explore a wider range of strategies—including both prosocial and competitive extremes—adolescents begin to converge toward stability, and adults overwhelmingly adopt stable, moderate, cooperative approaches to sustain negotiation success.

Figure 9: Clustering of proposer strategies in the ultimatum game.



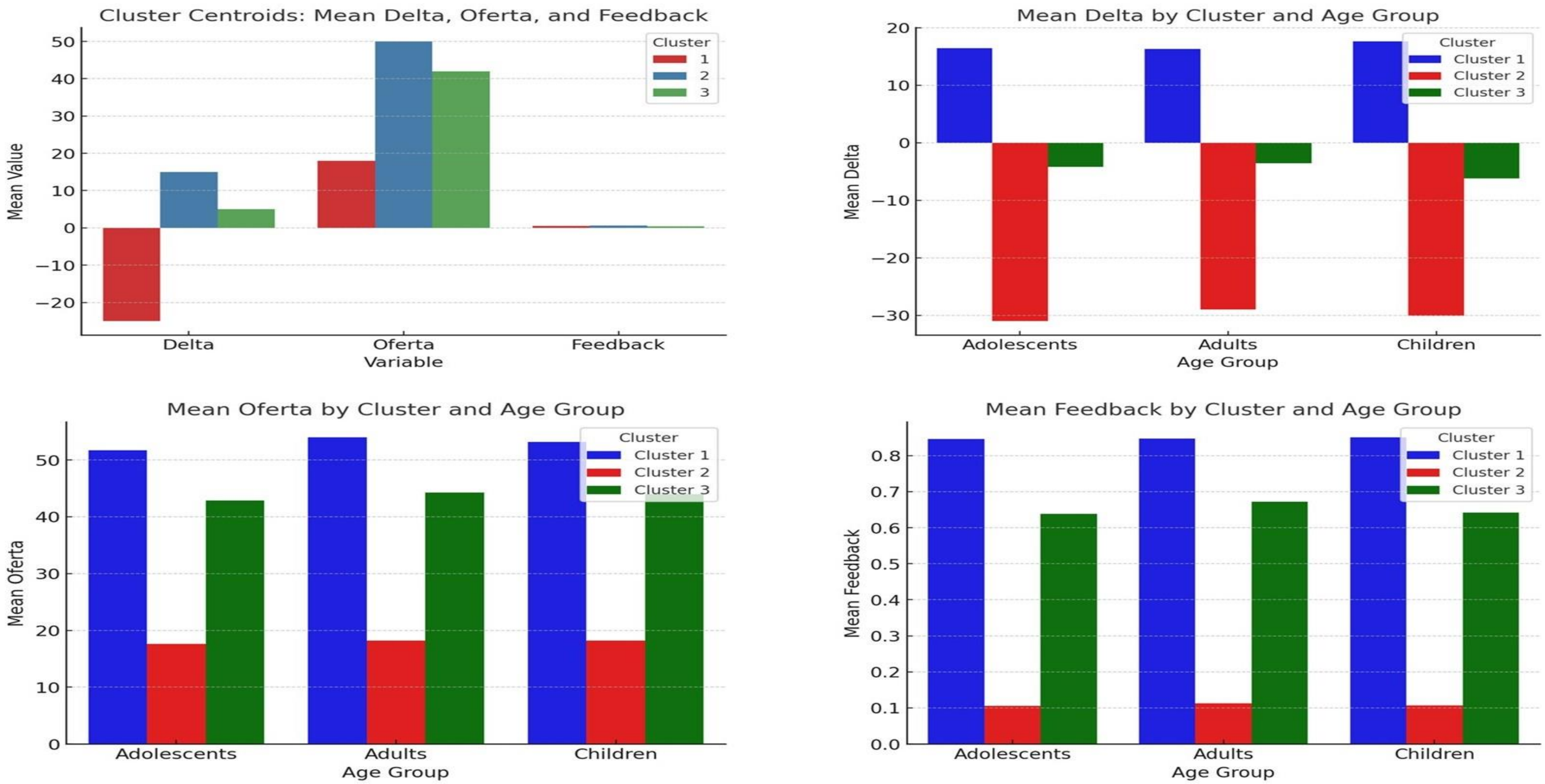
Top left: K-means clustering of offer adjustments (Delta) and offer size (Oferta) identifies three distinct behavioral clusters: Cooperative (Cluster 1, red), Competitive (Cluster 2, green), and Stable (Cluster 3, blue).

Top right: 3D visualization of clusters incorporating Delta, offer size, and acceptance rates (Feedback), illustrating clear separation of behavioral profiles.

Bottom left: Elbow method analysis of within-cluster sum of squares (WCSS) confirms three as the optimal number of clusters.

Bottom right: Proportional distribution of clusters by age group shows that stable strategies dominate across all groups, while children display greater heterogeneity, with higher proportions in cooperative and competitive clusters compared to adolescents and adults.

Figure 10: Cluster centroids and age-group comparisons of proposer strategies.



Top left: Cluster centroids showing mean values of offer adjustments (Delta), offer size (Oferta), and acceptance rates (Feedback), distinguishing Cooperative (Cluster 1, blue), Competitive (Cluster 2, red), and Stable (Cluster 3, green) strategies.
Top right: Mean Delta (adjustments) by cluster and age group indicates strong positive adjustments in Cooperative participants, sharp negative adjustments in Competitive participants, and minimal changes in Stable participants.
Bottom left: Mean offers (Oferta) by cluster and age group reveal that Cooperative participants consistently propose the highest offers, Competitive participants the lowest, and Stable participants intermediate offers across age groups.
Bottom right: Mean feedback (acceptance rates) by cluster and age group demonstrates that Cooperative strategies achieve the highest acceptance rates, Stable strategies moderate rates, and Competitive strategies the lowest rates, consistent across developmental groups.

3.11. DISCUSSION

This study examined developmental trajectories of social decision-making in the UG, focusing on whether proposers integrate prior feedback, how strategies differ across age, and whether these differences reflect maturational changes in ToM and EFs.

Stability Versus Feedback Integration

A central hypothesis was that proposers would adjust offers based on feedback, consistent with reinforcement learning accounts of social decision-making (Rangel et al., 2008). Our findings present a mixed picture. On the one hand, the delta model suggested that rejections prompted proposers to increase subsequent offers, indicating reactivity to negative outcomes. On the other hand, the sequential mixed-effects analysis revealed that feedback explained little trial-to-trial variance, suggesting limited reliance on immediate past experiences. This discrepancy suggests that while participants are sensitive to salient negative outcomes (rejections), their broader decision-making is anchored in stable fairness preferences, rather than continuous learning. This interpretation aligns with theories emphasizing the rigidity of fairness-based decision rules over trial-level adaptation (Fehr & Schmidt, 1999; Camerer, 2003).

Developmental Trajectory of Negotiation

Across analyses, we observed a clear developmental trajectory. Children showed the greatest variability, oscillating between cooperative and competitive offers. This pattern may reflect exploratory decision-making and the ongoing development of integrating others' outcomes into one's own (Crone & Dahl, 2012; Steinbeis, 2018). Adolescents displayed a stronger competitive tendency, with lower offers and greater variability, consistent with accounts linking adolescence to heightened social comparison, peer sensitivity, and risk-taking in social contexts (Blakemore & Mills, 2014; van den Bos et al., 2013). In contrast, adults exhibited the most consistent and fairness-oriented behavior, clustering around equal splits and maintaining stable acceptance rates. This trajectory supports the view that as ToM and EFs mature, individuals increasingly integrate fairness norms into their decisions (Carlson & Zelazo, 2021; Lecce et al., 2019).

Reconciling Contradictions Across Models

Although sequential models indicated weak trial-level feedback integration, the Markov chain analysis showed that acceptance stabilized as the dominant long-term state, suggesting that proposers adapt sufficiently to maintain cooperative outcomes. The clustering analysis further reinforced this interpretation: most participants fell into a Stable strategy group, characterized by moderate offers and minimal adjustments, while smaller groups adopted Cooperative or Competitive strategies. Together, these findings suggest that UG behavior reflects both stable, norm-driven preferences and context-dependent corrections, with age shaping the balance between variability, competitiveness, and stability.

Developmental Interpretation and Social Sensitivity

These results can be situated within developmental models of ToM and social cognition. Children's variability may reflect immature integration of others' payoffs, while adolescents' competitiveness could signal social sensitivity expressed through status-seeking and risk-taking (Crone & Dahl, 2012). Importantly, ignoring others' gains in certain contexts may not reflect a lack of ToM, but rather a contextually adaptive form of "social sensitivity," where prioritizing one's own payoff communicates competitiveness or dominance (Blakemore & Mills, 2014). Adults' preference for fairness and stability reflects the consolidation of ToM and EFs, facilitating consistent prosocial decision-making (Steinbeis, 2018; Zelazo & Müller, 2002).

Several limitations should be noted. First, the age ranges used may obscure finer-grained developmental transitions, especially within adolescence. Second, the UG is a simplified paradigm, which may not fully capture real-world negotiation dynamics. Finally, we did not account for gender or cultural differences, which have been shown to shape fairness preferences (Henrich et al., 2006).

To conclude, our findings indicate that social decision-making in the UG is shaped more by stable fairness preferences than by trial-level reinforcement learning. Developmentally, behavior shifts from children’s exploratory variability, through adolescents’ competitive tendencies, to adults’ fairness-oriented stability. These results support the view that the maturation of ToM and EFs underpins a trajectory toward stable, cooperative negotiation strategies (Carlson & Zelazo, 2021; Crone & Dahl, 2012). Although proposers show limited reliance on immediate feedback, long-term interaction dynamics favor cooperation, suggesting that the developmental maturation of social cognition promotes both strategic consistency and prosocial outcomes.

4. General Discussion and Conclusions

This thesis examined the developmental trajectory of social decision-making by integrating theoretical perspectives on ToM, EFs, and social preferences (Study 1) with empirical analyses of fairness-based negotiation behavior in the UG across childhood, adolescence, and adulthood (Study 2). By combining conceptual and experimental approaches, it contributes to a more comprehensive understanding of how individuals integrate their own and others' preferences when navigating cooperative and competitive contexts.

Study 1 provided the theoretical foundation, highlighting that ToM development depends on EF capacities such as inhibitory control, working memory, and cognitive flexibility (Carlson & Zelazo, 2021; Zelazo & Müller, 2002). These abilities allow individuals to represent, evaluate, and integrate social preferences—understood as motivations to maximize fairness, reciprocity, or self-interest that vary across contexts. Social preferences emerge early in life but continue to evolve through adolescence and adulthood, shaped by neurocognitive maturation, social experience, and cultural expectations (Fehr & Schmidt, 1999; Wellman, 2014). Study 2 tested these insights using behavioral models of UG proposer strategies. Results showed that children displayed the greatest variability, alternating between cooperative and competitive responses, reflecting exploratory behavior and high reactivity to feedback. Adolescents exhibited a pronounced competitive orientation, consistent with evidence linking adolescence to heightened risk-taking and sensitivity to social comparison (Crone & Dahl, 2012; Steinberg, 2010). Adults demonstrated the most stability and fairness-oriented strategies, aligning with the idea that mature ToM and EF capacities foster consistent cooperative decision-making (Giovagnoli, 2019; Marchetti et al., 2019).

Across models, feedback emerged as a nuanced factor. The delta models revealed that accepted offers robustly increased subsequent proposer behavior, suggesting that feedback does matter. Yet sequential analyses showed little reliance on trial-by-trial adjustments, and Markov models demonstrated that acceptance stabilized over the long run. Together, these findings indicate that while feedback shapes general behavioral tendencies, social decision-making is primarily guided by stable preferences rather than immediate reinforcement. Clustering analyses confirmed this heterogeneity, identifying Cooperative, Competitive, and Stable strategies, with the Stable cluster dominant across all age groups and the Competitive cluster most frequent among children and adolescents.

The results support the view that ToM and EF development jointly scaffold fairness-based negotiation strategies. Importantly, this relationship should be considered in light of the complexity of social stimuli that individuals must process. From a developmental perspective, EFs and ToM interact to support increasingly sophisticated levels of social integration: from the detection of basic perceptual cues such as facial expressions and gaze direction (Baron-Cohen et al., 2001; Saxe & Kanwisher, 2003), to the interpretation of others' intentions and beliefs

(Frith & Frith, 2006; Wellman, 2014), and ultimately to abstract, multilevel integration of self–other preferences in cooperative or competitive exchanges (Decety & Sommerville, 2003). The ability to handle these layers of complexity may explain why children often appear reactive and variable, adolescents competitive and exploratory, and adults increasingly stable and fairness-oriented. This developmental trajectory reflects not only cognitive maturation but also the growing capacity to integrate richer and more abstract social stimuli into decision-making.

Crucially, the limited reliance on immediate feedback challenges reinforcement learning accounts, suggesting instead that social negotiation reflects a balance between stable social norms and context-sensitive adjustments (Ruff & Fehr, 2014). ToM may play a key role here by allowing individuals to form relatively stable expectations about others' behavior, reducing the need for constant recalibration. Adults' greater stability thus appears to reflect both cognitive maturity and the consolidation of fairness as a guiding norm for interaction.

This thesis addresses a gap in the literature by bridging theoretical models of ToM development with empirical bargaining behavior. Previous work often emphasized one side—either the cognitive foundations of ToM or the behavioral outcomes of negotiation games. By combining a systematic review (Study 1) with advanced statistical modeling of UG data (Study 2), the current work provides a more integrated account of how cognitive, affective, and social processes interact across development to shape fairness-oriented strategies.

Several limitations must be noted. First, the age groups were relatively broad, limiting the ability to capture finer-grained developmental transitions (e.g., early vs. late adolescence). Second, the UG is a simplified paradigm that may not fully capture the complexity of real-world negotiations. Third, cultural differences in fairness norms and potential gender influences were not analyzed, though both may play important roles in shaping social preferences (Henrich et al., 2005; Giovagnoli, 2019). Finally, the behavioral focus of this work leaves open the question of the neural mechanisms underlying these developmental patterns, which future research should address using neuroimaging and psychophysiological approaches.

Finally, the two studies converge on the conclusion that social decision-making matures toward stability and fairness across development. Children are exploratory and variable, adolescents lean toward competitive strategies, and adults consolidate cooperative approaches. Feedback influences proposer behavior but does not operate as a trial-by-trial learning mechanism; rather, decision-making appears guided by stable preferences shaped by cognitive and social development. Integrating the complexity of social stimuli into the EF–ToM framework further clarifies this trajectory, showing that developmental change reflects not only the growth of abstract reasoning but also the ability to flexibly integrate multiple levels of social information. This thesis thus contributes both theoretically and empirically to our understanding of the interplay between ToM, EFs, and social preferences across the lifespan, offering a foundation for future investigations into how individuals learn to balance self-interest and cooperation in increasingly complex social environments.

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