Assessing and Training Temporal Relational Responding in Children

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Declaration Regarding the Work

I, the **Candidate**, certify that the Thesis is all my own work and that I have not obtained a degree in this University or elsewhere on the basis of any of this work.
This thesis is the result of my own investigations, except where otherwise stated.

This thesis is the result of my own investigations, except where otherwise stated. The following chapter includes work conducted in collaboration with other students:

- Chapter 6 (Study 4) includes work conducted in collaboration with Deirdre Barry, ABA MSc student.
    - Co-designed assessment and training protocol, assisted with analysis and write-up

Signed: ______________________ Date: 21/07/2023

Abstract

Time is a fundamentally important dimension of human experience and responding adaptively in terms of this dimension is critical to human personal and societal functioning. However, there is an important distinction to be made between responding to time as a physical or nonarbitrary dimension of existence and time as an abstract concept. It is the latter that is critical to the type of self-knowledge and societal organization that is unique to human life. Relational frame theory (RFT) sees relational framing, and temporal relational framing in particular, as key to this uniquely human level of responding. Temporal relational framing is a form of derived relational framing that involves responding under the control of contextual cues such as the words "before" and “after” to stimuli in terms of their directional displacement along a temporal dimension (e.g., if taught that A is after B; then derive that B is before A).

Important skills such as sequencing events, planning, time understanding, or talking about the past or future typically involve temporal relations. Accordingly, relational responding in the presence of temporal relational cues such as “before” and “after” is an important building block to more complex repertoires from an RFT perspective. Existing psychological research on temporal relations is mostly composed of descriptive studies and limited to investigations with age-level performance. Moreover, although previous RFT studies have taught several other varieties of relational responding, little work has yet been done in the case of temporal relational frames. The current thesis aimed to extend research in this area by conceptualizing how time as an abstract concept can be approached from an RFT perspective, and by developing RFT-based assessment and training procedures for temporal relational framing in children.

In support of these overall objectives, a narrative review and conceptual analysis (Chapter 2) was first done, which had three primary aims. The first aim was to summarize the existing psychological research into time-related skill sets in humans given the vast areas of investigation within this domain. The second aim was to explain temporal relational framing and the present state of relevant research into this skill. The third aim was to conceptually explore how the RFT approach to human temporal responding might amplify and extend the existing research base, in particular with respect to the acquisition and training of key aspects of temporal responding.

Study 1 (Chapter 3) was an empirical starting point based on one area of need identified in Chapter 2. The aim of Study 1 was to assess performance on a test of temporal relational responding in young children at increasing levels of complexity. Twenty-five typically developing children between 3-8 years were assessed on tasks of nonarbitrary (i.e., based on physical events) and arbitrary (i.e., based on contextual cues only) temporal relations. Nonarbitrary testing involved responding to observed sequences of stimuli and answering “before” and “after” questions about the order. Arbitrary testing was conducted using an adapted version of a relational evaluation procedure (REP) format which involved vocally responding to “before” and “after” questions about a presented temporal relational network across many exemplars (Kirsten & Stewart, 2022). Additionally, a transformation

of stimulus function was assessed on trials that involved performing motor actions in a particular sequence based on the presented relational network. Results showed a correlation between overall performance across temporal relational responding tasks and age. Performance on nonarbitrary "before" and "after" trials improved similarly with age whereas with arbitrary relations, participants performed much more poorly on "after" trials than on "before" trials and some interesting cohort specific patterns were also seen.

The data from Study 1 provided insight into how children of various ages may respond on temporal relational responding tasks; however, it remained unclear whether a behavioral training approach could be used improve performance. Study 2 (Chapter 4) aimed to develop a training protocol for teaching derived temporal relations in young children. Previous research has shown that multiple exemplar training (MET) can be used to train relational framing in children, though no work has been done specifically with temporal frames. Informed by the results of Study 1, this second study trained two typically developing 6-year-olds in derived temporal relational responding using a MET procedure in a nonconcurrent multiple baseline design. Study 2 used a similar REP format as in Study 1 in which various relational networks were shown and participants vocally answered "before" and "after" questions about the presented relations. Training involved reinforcement and error correction procedures for correct and incorrect responding, respectively. Following training, both participants reached criterion levels and passed generalization tests for both mutual and combinatorial relations with untrained stimuli and maintained performance four-weeks after training was finished.

Study 3 (Chapter 5) aimed to replicate and extend Study 2. A similar procedure was used as in the previous study but now with the inclusion of a protocol for training and testing of sequenced responses to allow for assessment of transformation of stimulus function. Three typically developing 5-year-olds were taught using MET in a combined multiple probe design across participants and responses. Training involved reinforcement procedures for correct responses and error correction procedures for incorrect responses. Following training, all participants reached criterion levels and passed generalization tests for mutual and combinatorial entailment, and transformation of function with untrained stimuli and maintained high overall performance four weeks following training.

In both Studies 2 and 3, participants were specifically taught to relationally respond to arbitrary temporal relations. Despite the importance of arbitrary relations, some individuals may present with more significant deficits in which beginning intervention at a nonarbitrary (i.e., physically based) level is needed prior to progressing to more abstract relations. Study 4 (Chapter 6) aimed to assess existing temporal relational responding skills in three adolescents with ASD and to evaluate the efficacy of an RFT-based multiple exemplar training (MET) procedure to teach nonarbitrary temporal relations (responding to sequential changes in the environment), which constitute an important foundation for derived temporal relations. Participants were taught using multiple exemplars of 2-image stimulus sequences and answered "before" and "after" questions regarding the observed order. Reinforcement and error correction procedures were applied for correct

and incorrect responding, respectively. Results indicated that all participants achieved mastery for nonarbitrary temporal relations following MET and that the skill generalized across novel stimuli.

The present thesis contributed to the literature base by providing an initial data set in terms of age-level responding on temporal relational responding tasks, creating a training protocol that can be used to teach temporal frames, and by extending research on temporal frames to new demographics. Additionally, several other time-related skills were identified as potential areas for further investigation from an RFT approach. In Chapter 7, the final chapter of this thesis, applied and theoretical implications of the data obtained, limitations of the studies, and potential future directions for research in this area are discussed.

Dedication

To Theo.

You are such an amazing joy.

I look forward to supporting you with your own dreams and adventures.

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Publications and Conference Presentations

Publications

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Manuscripts Accepted for Publication

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List of Abbreviations

A	After
AARR	Arbitrarily applicable relational responding
ABA	Applied behavior analysis
B	Before
CE	Combinatorial entailment
CFTQ	Child's Future Thinking Questionnaire
C_{func}	Functional contextual cue
CR	Conditioned response
C_{rel}	Relational contextual cue
CS	Conditioned stimulus
DRL	Differential reinforcement of low rate
DRR	Derived relational responding
EBI	Equivalence-based instruction
FI	Fixed interval
HDML	Hyperdimensional multilevel
IOA	Interobserver agreement
ME	Mutual entailment
MET	Multiple exemplar training
MTS	Match-to-sample
NA-2	Nonarbitrary-2 stimuli
NA-3	Nonarbitrary-3 stimuli
NARR	Nonarbitrary relational responding
PPVT-4	Peabody Picture Vocabulary Test—Fourth Edition
REP	Relational evaluation procedure
ROE-M	Relating, orienting, evoking, and motivating
RFT	Relational frame theory
SET	Scalar expectancy theory
TONI-3	Test of Nonverbal Intelligence—Third Edition
ToF	Transformation of function
ToF-ME	Transformation of function via mutual entailment
ToF-CE	Transformation of function via combinatorial entailment
TRA	Temporal relations assessment
UCR	Unconditioned response
UCS	Unconditioned stimulus
WAIS-III	Weschler Adult Intelligence Scale—Third Edition
WCST	Wisconsin Card Sorting Test

Chapter 1.
Introduction and Background

Portions of this chapter have been accepted for publication:

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Responding to how events are temporally related to each other is a key skill set that underlies many complex behavioral repertoires such as telling time, sequencing events, planning, setting goals, problem solving, time-management, and perspective taking. In socioverbal communities, this kind of behavior is typically evoked by words such as, “before/after,” “now/then,” “earlier/later,” etc., which signal a temporal relation between events (e.g., March is before April, lunch is sooner than recess). Relational frame theory (RFT; Hayes, Barnes-Holmes, et al., 2001) sees this type of responding as verbal and more specifically as a category of relational framing referred to as temporal relational framing (Hayes, Fox, et al., 2001). The purpose of this thesis is to investigate this concept by reviewing existing relevant research, carrying out a set of studies relative to the needs identified in the literature, and exploring potential future directions in this area.

Over the course of this research program, this project sought to contribute to existing knowledge by a) identifying specific temporal skill sets in humans of which RFT might offer analysis; b) extending the current research on temporal relations to new populations (neurotypical children and autistic adolescents); c) creating an assessment procedure that can be used to determine skill level with temporal relations; and d) establishing effective training methods for teaching temporal relational responding when this skill is still emerging.

The chapters of this thesis describe the research journey aligned to these objectives. In the present chapter, an overview of the philosophical and theoretical frameworks underpinning this thesis is first provided. Chapter 2 includes a narrative review of the literature on temporal skills from various psychological approaches. In conjunction with this review, a conceptual analysis is provided by laying out how RFT might be applied in terms of research and practice of temporal skill sets. Chapters 3-6 then focus on one area of application identified in Chapter 2: assessing and training temporal responding with “before” and “after.” Chapter 3 describes the implementation of an assessment procedure for multiple levels of temporal relational responding across different ages. Chapter 4 discusses developing and piloting a training protocol to examine the efficacy of RFT-based procedures for training skills that had not yet been acquired based on findings in Chapter 3. Chapter 5 describes how the training protocol was revised and expanded for replication with slightly younger participants using a stronger experimental design. Chapter 6 details the application and adaptation of the assessment and training procedure for temporal relational responding for autistic participants. Lastly, Chapter 7 summarizes the key findings of this research program, the theoretical and applied implications, limitations, and directions for future work.

Philosophical Assumptions

An overview of the philosophical assumptions of this approach is first made as the philosophy and scientific goal presented here may differ from other psychological approaches that investigate temporal skill sets. While the phenomenon of interest overlaps, there are distinctions between how the relevant events are studied and what the central goal of the analysis is. Making known these philosophical differences is important when communicating between disciplines as our different truth criteria give rise to different analyses and interpretations as well as provide a useful context for the evaluation of a scientific work (Hayes et al., 1999).

Pepper (1942) presented a selection of world views that constitute systems by which analyses of the world, or a particular phenomenon of interest are understood and interpreted. Although Pepper's work was originally used to discuss philosophical systems, his framework is also relevant to behavioral science as pre-analytic assumptions may differ across scientific perspectives concerning the nature of reality, what should be analysed, or even how science should be carried out. These pre-analytic assumptions are influential to theory, methodology, and scientific interpretation (Levin et al., 2016). Some researchers have found applying Pepper's work to the science of behavior to be useful as the underlying philosophical assumptions of different psychological perspectives share similarities to the world views he described (Hayes et al., 1988)[1]. World views were not considered to be better or worse than each another, but rather were seen to encompass different views and objectives.

Table 1.1

Summary of World Views

World view	Root metaphor	Truth criterion	Characteristics	Question asked (Dilworth-Anderson et al., 2005)
Mechanism	Machine	Correspondence	Analytic / Integrative	"How does it work?
Formism	Similarity	Correspondence	Analytic / Dispersive	"What is it like?"
Organicism	Developing organism	Coherence	Synthetic / Integrative	"How does it develop?"
Contextualism	Act-in-context	Successful working	Synthetic / Dispersive	"How is it happening?"

The four world views Pepper described are: mechanism, formism, organicism, and contextualism (Table 1.1). Each world view stems from a root metaphor for describing the nature of phenomena (ontological assumptions) and has its own truth criterion for determining the validity of analyses of phenomena (epistemological assumptions). Formism and mechanism are analytic (reductionistic) while organicism and contextualism are synthetic (holistic). Mechanism and organicism are integrative (facts are placed into a determinate structure) while formism and contextualism are dispersive (facts are interpreted as they come). Each of these world views is explained below. For illustration, the example of "planning"—a behavioral repertoire relevant to the

[1] Some authors have offered critiques and discussed potential limitations with applying Pepper's framework to behavioral science (see for example, Capaldi & Proctor, 1994; Dixon & Belisle, 2021). This framework is included in the current thesis as it provides a reasonably informative framework for discussing comparisons between goals and priorities within different psychological approaches when investigating similar phenomena.

concept of time—is used to show how each world view may approach and analyze this phenomenon slightly differently.

Mechanism uses the machine as a root metaphor and a truth criterion of correspondence. A machine, such as a computer, is made of separate parts that are related together and then when acted upon by a force, the machine functions in a particular way. The chief goal of the scientist is to explain how the machine works. A constructed model of a phenomenon is tested and considered true to the extent it corresponds with how the world actually is. When examining behavior, this world view may be recognized in various cognitive approaches (e.g., a cognitive model of planning might be formed and tested). For example, a machine (the organism) is seen to contain discrete, interrelated parts (e.g., attention, working memory, executive function, domain knowledge) while a force/causal agent (e.g., a problem scenario is presented) propels some type of effect or output to occur (e.g., a plan is formed). The model of the phenomenon is considered true to the extent it accurately predicts behavior.

Formism uses similarity as its root metaphor and correspondence as a truth criterion. Similarity here refers to the recurrence of recognizable forms (Hayes et al., 1988); that is, a certain phenomenon of interest is examined and categorized in terms of its similarity or dissimilarity to other phenomena. The goal of the scientist is to describe the essence of what the phenomenon is like. With behavior, the study of personality traits may be an example (e.g., examining which people tend to plan more). An explanation as to why a person tends to plan for events and activities may be that they are considered to have more of a conscientiousness trait (form). If a person tends to be a "planner," the scientist may predict that they would score similarly on measures of conscientiousness as others who tend to plan (recurrence of the recognizable form). The category is true to the extent that it corresponds with the observed phenomena.

Organicism uses the root metaphor of the developing organism (i.e., a living system) and a truth criterion of coherence. The process of organic development involves the unfolding of a phenomenon over time, such as a seed growing into a plant. The scientist seeks to explain and predict the orderly, sequential progression of the event or system. With behavior, developmental stage models in psychology may align with this world view (e.g., Piaget's stages). A proposed model of stages is analyzed based on how well it predicts an orderly reality. For example, a model might seek to explain how the ability of planning unfolds in development and at what ages certain planning skills are observed. If contradictions exist (e.g., a particular planning skill does not reveal a developmental trend), then the "organic whole" has not yet been realized. As facts about the presumed orderly process are obtained, an analysis is considered true to the extent that all the facts cohere with one another, leading to a full picture of the organic whole.

Contextualism uses the root metaphor of the ongoing act-in-context and has a truth criterion of successful working. Events are considered inseparable from their context (hence the hyphenation with "act-in-context") and therefore a scientist seeks to understand an event in relation to its context. For instance, the unit of the discriminated operant within behavior analysis is an example as each component (antecedent-behavior-consequence) is defined and analyzed by its relation to the other components. Acts-in-context can be integrated or divided in an infinite number of ways, so truth is understood only in a relative sense (Gifford & Hayes, 1999). The behavior of making a plan can be analyzed in the context of going to the store, going to the store as part of hosting a party, and so on.

In contextualism, the purpose of the act is of primary importance. Any act has a functional purpose in its situational and historical context. A "correct" behavior in one context may not be as workable in another. Planning for the future (e.g., an upcoming vacation) may be more desirable in one context (e.g., to get the cheapest airfare) and less desirable in another context (e.g., when being spontaneous is a priority). In this example, a contextual perspective analyses planning by attending to the historical and situational contextual features in which it occurs. Since all behavior is situated in context, this also means that the scientist doing the analyzing is itself an act-in-context. Therefore, a theory or analysis of behavior is true or not insofar as it "works" to achieve the pre-established goal. Accordingly, an analysis of behavior is useful to the extent it aids the scientist in achieving their explicit goal.

One variety of contextualism, *functional contextualism*, has an explicit goal of prediction and influence of behavior. The extent to which this goal has been achieved can be evaluated across the dimensions of precision, scope, and depth. Precision refers to the degree in which a phenomenon can be explained in a limited number of ways. Scope describes the degree to which an analysis can be applied to a range of phenomena. Depth refers to the consistency between an analysis made and findings from other areas or levels of analysis (Biglan & Hayes, 2016). More broadly, functional contextualism is a variant of the larger philosophical tradition of pragmatism.

Functional contextualism is advantageous for the study of human behavior due to its unique emphasis on influence (Biglan & Hayes, 1996). The other world views also seek to predict behavior through theoretical accounts, but it is not necessarily derivative that a given model can be used to influence behavior; especially if a model appeals to explanations only involving variables that cannot be manipulated (e.g., an internal timing mechanism, psychological traits, age). The additional focus on influence insists on the contextualist to include variables that can be directly changed (Hayes & Brownstein, 1986). The prediction of behavior can indeed provide informative findings but nevertheless, a functional contextual approach argues that the analysis is incomplete if stopped there. Biglan and Hayes (1996) argued that in order to change a behavior, one must target variables that can in fact be altered. Ultimately, to achieve a scientific goal of both prediction and influence of a behavior, an analysis must include adjusting the context in which that behavior occurs. Changing environmental variables that are sensitive to the historical and situational contexts of individual learners specifically provide practical approaches to lead to socially significant behavior change—a central aim of applied behavior analysis (ABA; Baer et al., 1968). While behavior analysis has been interpreted both mechanistically as well as contextualistically, researchers within the field of relational frame theory (RFT), which provides the theoretical background to the present thesis, see behavior analysis and hence also RFT as forms of functional contextualism. From this point of view the explicit goal of behavior analysis is prediction-and-influence of behavior in general while the explicit goal of RFT is prediction-and-influence of human language and cognition.

Relational Frame Theory

Relational frame theory (RFT) is a contextual behavior analytic account of language and cognition (Hayes, Barnes-Holmes, et al., 2001) and is the theoretical foundation of this thesis. The following section provides a brief overview of RFT in terms of its background, key concepts, and empirical research.

Background to RFT

Historically, RFT emerged from limitations in Skinner's conceptual approach to verbal behavior and empirical findings on rule-governed behavior and stimulus equivalence. Skinner defined verbal behavior as behavior reinforced through the mediation of a listener trained by the verbal community to do so (Skinner, 1957a). Challenges to this definition were raised in two primary ways. First, the definition was too broad as it would include the behavior of any organism that is reinforced by a listener that is trained to do so. Second, it was non-functional as the behavior of the relevant organism (the speaker) relies on the history of a different organism (the listener).

Empirical findings on rules also uncovered important considerations relevant to language. Research on fixed interval (FI) reinforcement schedules revealed that humans with verbal abilities appear to respond differently than infants and other organisms (Bentall et al., 1985; Pouthas, 1985). While rules presented by experimenters appeared to influence performance, so did the production of self-generated rules (Lowe et al., 1983; Rosenfarb et al., 1992; Vaughan, 1985). Studies also demonstrated sensitivity effects as a behavior that is controlled by a rule can continue to occur even when the direct contingencies have been changed (Hayes et al., 1986). A clear behavioral account of language itself appeared relevant in order make sense of these findings and clarify conceptually what verbal stimuli are, but such an account was lacking at the time.[2] The research on stimulus equivalence however, provided new insight into how language could be approached from a behavioral perspective.

Sidman (1971) provided the first empirical demonstration of stimulus equivalence in a seminal study that aimed to teach a participant with a cognitive impairment to read. The participant could already match spoken words to pictures (A→B) and was taught to match text to spoken words (C→A). What incidentally resulted from this training though, was the subsequent emergence of

[2] Skinner (1969) defined a rule as a verbal stimulus that specifies a contingency and suggested that a rule functions as a discriminative stimulus in relation to the listener. A few issues are evident. Since Skinner's definition of verbal behavior itself was too broad and not functional, it was unclear what would be considered a "verbal stimulus" within a rule. Secondly, rules cannot simply be discriminative stimuli, as stimuli become discriminative when they were present when a response has been differentially reinforced in the past. This issue is clearly evidenced when novel rules control responding, as these rules have not been contacted previously. Additionally, Skinner's account of verbal behavior considered the speaker but deemphasized the listener. This is problematic in relation to rule-governed behavior, as the listener is the one who understands and follows the rule. As such, there was not a way to define, in a technical sense, what is meant by "specifies" (Hayes & Hayes, 1989).

completely untaught responses of matching pictures to text (B→C) and orally naming the printed words (A→C). This experiment demonstrated that sets of stimuli without formal similarity can be derived as equivalent without having to directly train every relation. These relations that emerged are defined as *derived* stimulus relations as they were never directly taught. Subsequent research showed stimulus equivalence and language are closely linked. Stimulus equivalence has been evidenced in humans at young ages while absent in non-humans (Sidman et al., 1982), has been correlated with verbal abilities (Devany et al., 1986), and has been found to show similar brain activation patterns as verbal fluency tasks (Dickins et al., 2001). Further evidence has shown that a psychological function of one stimulus that is in a derived equivalent relation to other stimuli may transfer to those stimuli without additional training. This transfer of function effect has been exhibited with both respondent and operant functions (de Rose et al., 1988; Dougher et al., 1994) and has been shown to occur in stimulus equivalence training approaches to teach language skills, such as making requests (Rehfeldt & Root, 2005).

RFT emerged as a conceptual account that specifically proposed in operant terms where stimulus equivalence came from and why it was related to language. It explained that stimulus equivalence and other (non-equivalent) forms of derived relational responding could be considered as learned patterns of generalized relational responding and that in fact such responding was the key operant that underlay language and cognition. Additionally, RFT provided an account for the impact of rules or language more broadly, arguing that the difference in responding between verbal and non-verbal organisms is underscored by the ability to derive relations.

Overview of RFT

Relational responding refers to behavior in which an organism responds to one stimulus in terms of its relation to another stimulus. According to RFT, this behavior can be divided into two varieties: nonarbitrary relational responding (NARR) and arbitrarily applicable relational responding (AARR) (see e.g., Stewart & McElwee, 2009).

Nonarbitrary and Arbitrary Relations

NARR is a type of relational responding in which an organism responds to one stimulus in terms of its physical or formal relation to another stimulus (Hughes & Barnes-Holmes, 2016). Selecting a stimulus physically the same as another (AKA identity matching) is an example of NARR. The second variety of relational responding, AARR, is a more abstract type of relational responding that is based not on the physical relation between stimuli but instead on contextual cues that specify the relation between the stimuli. For example, imagine I tell someone unfamiliar with US currency that a dime is worth more than a nickel and they subsequently produce the untrained relational response that a nickel is worth less than a dime. In this case I have used the cue “more than” to specify for this person a relation of comparison between two stimuli without any physical coins being present and they have produced an untrained relational response in accordance with the cued relational pattern (i.e., they have “derived” the untrained relation). Such relations are “arbitrarily applicable" in the sense that they can be applied to any stimuli irrespective of their actual physical properties (Blackledge, 2003). While NARR has been demonstrated both with humans and non-humans (Giurfa et al., 2001; Harmon et al., 1982), evidence for non-humans showing AARR is weak (Dugdale & Lowe, 2000; Galizio & Bruce, 2018; Hayes, 1989; Lionello-DeNolf, 2009; Sidman et al., 1982) or controversial at best (Dymond, 2014; Hughes & Barnes-Holmes, 2014; McIlvane, 2014; Zentall et al., 2014). Even in the studies showing them to pass such tests, the demonstration is relatively limited (Schusterman & Kastak, 1993; Urcuioli, 2008). Meanwhile, humans readily pass such tests from a very early age and go on to show multiple complex patterns of derived relations (Kirsten & Stewart, 2022; Lipkens et al., 1993). Due to this, it is this latter skill (AARR) that RFT considers as particularly relevant to complex human behavior.

Patterns and Properties of AARR / Relational Framing

RFT suggests that humans can show a variety of patterns of AARR including, for instance, coordination (a cup is like a mug), distinction (lemons are different than limes), opposition (north is opposite to south), comparison (winter is colder than summer), spatial (the toy is under the couch), temporal (morning is before night), and hierarchical (a cat is a type of animal). These different patterns of AARR are referred to as "relational frames" (Hayes, Fox, et al., 2001) based on the analogy of a picture frame in which the content can differ while the frame or outline remains the same, with different types of relations (e.g., same, different, opposite, etc.) constituting different ways in which stimuli (as the content) can be framed. All frames involve three core properties: mutual entailment, combinatorial entailment, and transformation of stimulus function. *Mutual entailment*, the reversibility of relations, is demonstrated, for instance, if a child is taught that coin A is worth less than coin B and then derives without further training that coin B is more than coin A. *Combinatorial entailment* is shown when relations are combined with other relations to produce novel untaught relations. For example, if a child is taught that coin A is worth less than coin B and that coin B is less than coin C, then they might derive that A is less than C and that C is more than A. *Transformation of stimulus function* refers to the empirical phenomenon wherein a particular function of a stimulus (e.g., discriminative, reinforcing, motivative, perceptual, eliciting, etc.) is changed or transformed based on a derived relation with another stimulus (Dymond & Rehfeldt, 2000). For example, imagine the child in the previous example has direct experience with coin A such that it has become an appetitive stimulus but no direct experience with coin C. After deriving that coin C is worth more than coin A, upon subsequently being given the choice of coin A or coin C the child is likely to pick coin C rather than coin A despite their previous history, based purely on the derived comparative relation. This property of AARR is particularly important from an RFT view as it demonstrates the manner in which language can impact behavior and it has been empirically shown with a variety of functions and relational patterns (Stewart & Roche, 2013).

Contextual Control and Acquisition of Relational Framing

Derived relational responses are under the control of environmental stimuli, referred to as contextual cues. RFT research has distinguished between two types of contextual cues: relational cues (C_{rel}), which come to control the type of relation derived (e.g., coffee is *better than* tea; a house *contains* a kitchen), and functional cues (C_{func}), which come to control the stimulus function to be transformed in accordance with the relation (e.g., imagine the *smell* of coffee; *picture* your kitchen). RFT suggests that contextually controlled AARR is an operant that is established through multiple exemplar training (MET), wherein a variety of stimuli are used as relata but the specific contextual cues remain the same.[3] Through a history of differential reinforcement, a child's relational responding comes under the control of such cues (Hayes, Fox, et al., 2001). For instance, Barnes-Holmes and colleagues (2004) used MET to train comparison relations in 4- and 5-year-old children. Sets of two or three novel coins were presented and the children were told a relation between the coins such as, "if this coin (points to coin A) buys more/less sweets than this coin (points to coin B), which would you take to buy as many sweets as possible?" Following differential reinforcement for accurate responding, participants demonstrated derived comparison framing in accordance with "more than/less than" cues and passed tests of generalization with novel stimuli. Several studies have shown that different patterns of AARR can be established and/or strengthened in various populations through MET, such as coordination (Rehfeldt & Root, 2005), distinction (Dunne et al., 2014), comparison (Berens & Hayes, 2007), opposition (Y. Barnes-Holmes et al., 2004), hierarchy (Ming et al., 2018), deixis (Gilroy et al., 2015), and analogy (Carpentier et al., 2002).

Recent Theoretical Advances in RFT

Barnes-Holmes and colleagues (2017; 2020) provided an updated model of the dynamics of relational behavior. The hyperdimensional multilevel (HDML) framework suggests that AARR can be experimentally analyzed along different levels and dimensions (Table 1.2)[4]. The HDML includes five levels of relational responding. *Mutually entailing* refers to the bidirectional relation between two stimuli (e.g., if A less than B, then B more than A). *Relational framing* involves the combining of

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[3] RFT suggests that AARR is operant behavior that is strengthened by a history of differential reinforcement in the presence of specific contextual cues. Operant behaviors can be seen to have four specific properties: they develop over time, are flexible/changeable, can be brought under antecedent control, as well as consequential control (Hayes, 1994; Hughes & Barnes-Holmes, 2016). Multiple studies have provided evidence of gradual acquisition of AARR in a variety of types of relations across childhood (Kirsten & Stewart, 2021; McHugh et al., 2004; Mulhern et al., 2017) while other studies have demonstrated that when certain relational framing repertoires are absent, they can be established through training (Y. Barnes-Holmes et al., 2004). The operant characteristic, flexibility (i.e., the behavior can be altered even after being learned), has also been shown with AARR. For example, O'Connor et al. (2011) taught participants to alternate between correct and incorrect responses in the presence of contextual cues. The different patterns of AARR that can be established is evidence for antecedent control as a wide variety of contextual cues can be established for responding. Consequential control of AARR has also been shown. For instance, Healy et al. (2000) manipulated the use of accurate and inaccurate feedback for AARR and demonstrated that both mutually and combinatorially entailed relational responses are sensitive to consequential control.

[4] The HDML framework also includes a proposed new conceptual unit of analysis referred to as the ROE-M (relating, orienting, evoking, and motivating). In this approach, instances of AARR involve the combination of relating stimuli in various ways (Crel properties), as well as orienting toward stimuli and the evoking of responses under appetitive or aversive control (Cfunc properties) within a context that includes dynamic motivating variables. The ROE-M is analyzed as a singular unit as relating, orienting, evoking, and motivating all influence one another. See Harte and Barnes-Holmes (2021) for an overview.

multiple mutually entailed relations (e.g., if A less than B, B less than C, then A is less than C and C is more than A). *Relational networking* involves the combining of different relational patterns (e.g., if A less than B, B less than C, C same as D, D same as E, then deriving that D and E are larger than A and B). *Relating relations* involves relating one derived relation to another derived relation (e.g., if A1 is less than B1, and A2 is less than B2, then it can be derived that the relation between A1-B1 is the same as the relation between A2-B2). *Relating relational networks* involves the relating of one relational network to another relational network (e.g., if A1 less than B1 and B1 same as C1, and A2 less than B2 and B2 same as C2, then it can be derived that relational networks 1 and 2 are the same).

Table 1.2

Levels and Dimensions in the HDML Framework

Levels	Dimensions			
	Coherence	Complexity	Derivation	Flexibility
Mutually Entailing	Analytic Unit 1	Analytic Unit 2	…	…
Relational Framing	…	…	…	…
Relating Relations	…	…	…	…
Relating Relational Networks	…	…	…	Analytic Unit 20

Relational responding can also be examined along four dimensions. *Coherence* refers to the extent to which a relational response is consistent with one's learning history. If a child has previously learned that "Monday is before Tuesday" and is later asked if Tuesday is after Monday, responding "yes" would be considered coherent with their learning history in terms of relating these stimuli. *Complexity* refers to how "detailed" the relational response is (e.g., number of stimuli or relations, types of relations). For instance, "Monday is before Tuesday" entails two relations ("before" and "after") which is more complex than a difference relation such as "Monday is different than Tuesday," which entails one relation ("different than"). *Derivation* refers to the degree to which a relational response has been practiced. The first instance of deriving "Tuesday is after Monday" would be considered high in derivation; as that response continues to be emitted, it progressively acquires a history of direct reinforcement, and the derivation becomes lower over time. *Flexibility* refers to the extent to which a relational response can be modified by the current context. If a child is now told, "Monday is after Tuesday," the faster they derive the relation in this new context, the more flexible their relational response is.

Key Research Findings on AARR

Evidence from multiple studies conducted over the past number of decades (see for example Hughes & Barnes-Holmes, 2016; Stewart & Roche, 2013) has been interpreted by RFT researchers as indicating that AARR is the critical repertoire that underpins symbolic language and cognition. For example, the development of AARR has been evidenced in humans as young as 17 months and parallels language development (Lipkens et al., 1993), and is correlated with verbal abilities (Barnes et al., 1990; Devany et al., 1986; Moran et al., 2014; Moran et al., 2015). Research involving neurophysiological methods has shown similar brain activation patterns between AARR and responding on verbal/semantic tasks including fluency (Dickins et al., 2001) and lexical decision making (Barnes-Holmes et al., 2005). Studies have also shown strong correlations between AARR and performance on standardized tests of cognitive abilities in adults (Colbert, Dobutowitsch, Roche, & Brophy, 2017; Colbert, Malone, Barrett, & Roche, 2020; O'Hora et al., 2005; O'Hora et al., 2008; O'Toole & Barnes-Holmes, 2009) and in children with and without disabilities (Belisle et al., 2018; Dixon, Belisle, & Stanley, 2018; Kirsten & Stewart, 2022). Other studies with school-age children have shown that training in relational skills may lead to improvements in performance on standardized tests of cognitive abilities (Amd & Roche, 2018; Cassidy et al., 2016; Cassidy et al., 2011; Colbert, Tyndall, Roche, & Cassidy, 2018; Hayes & Stewart, 2016; McLoughlin, Tyndall, Pereira, et al., 2020). Most recently, a randomized control trial evaluated the effects of training relational skills with 73 school-aged autistic children receiving ABA services (Dixon et al., 2023). Overall, the data showed that the group that received relational training made greater skill gains and scored higher on standardized intelligence measures compared to the treatment as usual group.

Over the past several decades, research inspired by RFT has continued to grow and the theory has accumulated strong empirical support (Dymond et al., 2010; M. O'Connor et al., 2017). RFT research has opened up a new behavioral approach to investigating human language and complex behavior (Stewart, 2016) including rules (Harte et al., 2020), analogies and metaphors (Foody et al., 2014), and perspective taking (Barnes-Holmes, McHugh, et al., 2004). Furthermore, evidence for the practical applied importance of RFT has been very prominent in this expanding program of work.

Summary

RFT is a contemporary behavior analytic approach to language and cognition that fits with the philosophy of functional contextualism, which specifies a scientific goal of both prediction and influence of behavior. While RFT emerged from a behavior analytic tradition, limitations with Skinner's analysis of verbal behavior, findings from research on rule-governed behavior, and the discovery of stimulus equivalence were specific milestones that paved the way for RFT. This approach emphasizes that the key to language and cognition is relational framing, the ability to derive relations between stimuli, irrespective of their physical properties. Relational framing is evidenced by the specific properties of mutual entailment, combinatorial entailment, and transformation of stimulus function and these properties can be observed across a variety of relational patterns that are under contextual control. Different levels of complexity of AARR can also be demonstrated, and instances of relating can be analyzed along different response dimensions like coherence, complexity, derivation, and flexibility. AARR is a generalized operant that develops over time, is changeable, and comes under the control of both antecedents and consequences. Relational responding repertoires emerge across development in naturalistic language contexts through exposure to sufficient multiple exemplars, while experimental research has shown that arranging systematic training conditions can improve these repertoires when underdeveloped or absent.

Chapter 2.
Time-Related Skills in Humans and Relational Frame Theory:
A Review and Conceptual Analysis

Portions of this chapter have been accepted for publication:

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Time is a fundamentally important dimension of human experience and responding adaptively in terms of this dimension is critical to human personal and societal functioning (Brislin & Kim, 2003; Grondin, 2008). We organize ourselves and our activities, both short and long term, in time. This has been true throughout human existence but it has become particularly important in the post-industrial era in which organization and coordination of human activity has become critical to societal functioning (Thompson, 1967; Whipp et al., 2002). All organisms are sensitive to time at some level as all organisms respond to changes in their environment (Block et al., 1999; Brannon et al., 2007; Gibbon, 1977). From habituation and sensitization, to classical and operant conditioning, time is a common factor across all learning processes. However, there is an important distinction to be made between responding to time as a nonarbitrary dimension of existence (i.e., to the experienced sequence of ongoing physical changes in the environment) and responding to time as an abstract concept (i.e., time as described in symbolic language such as, "You'll have to wait a few minutes" or "I have a lot of time on my hands") (Hayes, 1992). It is the latter that is critical to the type of self-knowledge and societal organization that is unique to human life. The purpose of this chapter is to explain this concept and discuss relevant research both in terms of what has been done as well as potential future directions, especially in terms of the acquisition and training of this repertoire.

Past Behavioral Research on Responses to Time in Humans

How humans experience time has been a subject of interest in philosophical, natural science, and social science disciplines (Arstila & Lloyd, 2014; Einstein, 1905; Evans, 2013; Gale, 2016; Grondin, 2010; Levin & Zakay, 1989; McTaggart, 1908; Piaget, 1971). Within behavior analysis, Skinner (1938) notably dedicated a chapter on the temporal discrimination of the stimulus in *The Behavior of Organisms* (see Lejeune et al., 2006 for a discussion). He elsewhere indicated that operant behaviors, like those seen in reaction-time experiments, can be affected by adding temporal properties to a contingency, such as by reinforcing responses that are made as quickly as possible or by only reinforcing responses that are delayed for a period of time (Skinner, 1953). Within behavior analytic work, rate could be considered a key dependent variable. However, measurement of rate is usually used as a means of assessing some other variable, such as reinforcement, rather than there being a focus on temporal responding itself. Nonetheless, some behavior analytic methods have been used to empirically explore the human response to time as an aspect of the environment.

Respondent Conditioning and Temporal Responding

Historically, both respondent and operant approaches have been used to study human responding to time across different ages. Early behavioral research examined temporally conditioned responses in infants with respondent conditioning procedures. This approach involved the presentation of a stimulus on a particular temporal interval followed by trials that omit the stimulus to test if the infant's conditioned response continues to occur around the time the stimulus would have been delivered (Colombo & Richman, 2002). Such a response is said to provide an indication of the infant's sensitivity to duration. For example, Brackbill and Fitzgerald (1972) temporally conditioned a pupillary reflex in 1-month-old infants. In their approach, changes in lighting were administered (e.g., 4s light on or 4s light off; UCS) at a constant 20s interval. They observed that these lighting changes elicited an unconditioned pupillary reflex (UCR) by the infants. Subsequently, they ran test trials in which the light changes (UCS) were not presented and found that the pupillary reflexes continued to occur, thus showing sensitivity to the passage of time as a conditioned stimulus (CS) by the production of conditioned pupillary response (CR). Researchers have also examined whether other responses such as heart rate deceleration might be temporally conditioned, but while some positive evidence has been provided, results have not been as clear or definitive as for the pupillary reflex (Colombo & Richman, 2002; Stamps, 1977).

Operant Conditioning and Temporal Responding

Operant procedures have also been used to evaluate sensitivity to different duration values with regard to various types of reinforcement schedules. In particular, studies with Fixed Interval (FI) schedules of reinforcement have shown notable differences in responding in humans compared to nonhumans. Whereas nonhuman organisms have been shown to demonstrate a “scalloped” response pattern (a pause after reinforcement followed by a gradual increase in response rate) on FI schedules (Ferster & Skinner, 1957), adult humans do not tend to produce this pattern. Instead, studies show that adult humans produce either high-rate or low-rate responding during the interval, and studies also show that this performance can be substantially influenced by instructions (Baron et al., 1969; Leander et al., 1968; Lippman & Meyer, 1967; Matthews et al., 1977; Weiner, 1964).

Other behavior analytic research with adults has investigated the effect of verbal behavior on temporal responding more specifically. One such example is from a study by Lowe et al. (1978). In one condition, participants could press a panel that illuminated a binary clock that only signaled the availability of reinforcement (the panel lit up green when reinforcement was available, and white when it was unavailable). In the second condition, participants could press a panel that produced a digital clock that showed the time since last reinforcement in minutes and seconds. The authors found that performance in the digital clock condition was similar to a conventional scalloped response pattern on FI schedules; however, performance in the binary clock condition did not show similar sensitivity to the temporal parameter of the reinforcement schedule. One possible reason for the difference as suggested by Lowe and colleagues, may be the presence of counting in the former condition. When presented with a questionnaire about the experimental task, all participants accurately indicated that the delivery of points was contingent on the passage of time. However, the binary clock participants also stated that they counted to themselves until they estimated the duration to be finished whereas the digital clock group did not report any use of counting.

Young children’s sensitivity to the temporal properties of contingencies have been evaluated using similar methods to those used with adults. These types of studies have typically involved tasks in which the delivery of a reinforcing consequence (e.g., cartoon presentation) is made contingent on the emission of a response (e.g., button pressing) in accordance with the respective reinforcement schedule. Research using Differential Reinforcement of Low-Rate (DRL) schedules has shown it to be difficult for young children to withhold their response during the interval. While training can decrease the response rate in young children, their behavior does not necessarily match the set duration interval (Pouthas, 1985). Research with FI schedules has revealed that children produce greater response variability compared to ratio schedules, and that they may either wait for the interval to elapse before responding or show high rates of button pressing during the interval (Bentall et al., 1985; Zeiler & Kelley, 1969). Bentall and colleagues (1985) in fact noted that the expected FI response pattern observed in non-humans is frequently observed in infants but that as children begin to acquire verbal behavior, their response patterns on such schedules begin to change. Particularly, by the age of 5 years, children demonstrated either high-rate or low-rate response patterns, which is similar to what is seen in adults. Darcheville et al. (1993) extended this work to even younger participants. They found that infants between 3-5 months demonstrate sensitivity to various duration values (10s-80s). These 3- to 5-month-olds all showed post-reinforcement pauses characteristic of FI schedules in basic animal research, whereas 9- to 23-month-olds produced greater variability in response patterns. Furthermore, these response patterns (i.e., waiting for the interval to elapse, high rates of response) have been observed to persist across training sessions if children did not receive verbal instructions with regard to the interval (Droit et al., 1990).

A number of additional studies suggest an effect of verbal abilities on responses to time in children. In one study that incorporated different verbal rules as instructions for button pressing (e.g., "press harder," and "press longer"), performance differed across age. Whereas 3-year olds pressed the button with increased force as well as duration when told to "press harder," 5½-year olds pressed with increased force but not for longer durations and were more accurate with temporal instructions ("press longer," Droit-Volet, 1998). There is support that providing training using temporal instructions (e.g., to attend to the interval) can improve performance with both FI schedules (Bentall & Lowe, 1987; Droit et al., 1990) and DRL schedules (Pouthas & Jacquet, 1987). Lejeune et al. (1992) showed that when temporal verbal instructions are provided to children, better performance on the timing tasks is observed compared to same-aged children that did not receive the verbal instructions. Pouthas and colleagues (1993) argue that this is evidence that timing performance can come to be controlled by acquired "abstract representations of time" in addition to control by direct contingencies. Additionally, they suggest that providing temporal "information" is not strictly limited to issuing instructions vocally. Better performance has also been observed when children were given a supplemental visual stimulus in the form of a series of small light bulbs that changed from green to red, which indicated the passage of time (Droit et al., 1991). The authors posit that the children in this study abstracted temporal information from this external clock as they verbalized self-formulated rules such as, "I must wait until the [lights] turn red." (Pouthas et al., 1993, p. 211).

While there appears to be evidence that verbal behavior can alter human responses to time, there has as yet been insufficient research examining exactly how it does so from a behavioral perspective. Learning to abstract rules that influence temporal responses appears relevant to language skills; however, it is not clear in a technical sense what this means and how this occurs. Beyond discriminating the durations of stimulus events, humans acquire further complex behaviors with time-related concepts. Critically, humans learn to organize events based on their temporal order and verbally construct sequences of past or hypothetical future events. Skinner (1957b) in fact suggested that verbal responses which describe a speaker's own past or future behavior are at least in part controlled by private stimuli and advocated for further analysis with respect to the variables that control these types of responses. Behavior analytic work has thus far insufficiently engaged on these more complex time-related repertoires in humans. In order to evaluate behaviors of this sort and other skills relevant to temporal understanding that seem to require verbal behavior, we suggest that an adequate functional analytic account of language and cognition is critical, and that relational frame theory (RFT) meets this criterion.

Temporal Relations: An Overview and Present RFT Research

RFT proposes that non-humans and humans experience time differently due to the fact that humans can respond to time verbally, that is, as described via symbolic language (Hayes, 1992). In RFT terms, this means engaging in AARR or relational framing with respect to time (Hughes & Barnes-Holmes, 2016) and RFT sees temporal relational framing as central in this respect.

Nonarbitrary and Arbitrary Temporal Relations

As with other relational frames, temporal relational responding has both nonarbitrary and arbitrarily applicable varieties. Hayes (1992, 1993) elaborated on this point when discussing a distinction between non-verbal and verbal time. In a nonarbitrary sense, time can be understood as a measure of change. This change is unidirectional in the sense that we always move from a "now" to a "new now." Non-verbal organisms experience this change through their direct contact with sequences of events in their environments. For example, a pigeon that has learned that in the presence of a particular stimulus order (e.g., a light that flashes green, then red, then blue) and not others that pecking a key results in obtaining food, has learned a temporal sequence through its direct experience. Different species including humans can learn through experience and respond to change in this nonverbal or experiential manner, although discriminating temporal sequences of this sort can take substantially more learning trials for non-humans (for a review, see Ghirlanda et al., 2017). As another example, a child may demonstrate nonarbitrary temporal relational responding in a context of being asked to repeat a set of actions shown by a model in a similar or different sequence to that shown by the model. The child is relationally responding in accordance with their actual experience of sequential change in this instance.

Learning to engage in arbitrarily applicable temporal relational responding (i.e., temporal relational framing), and hence to respond to time verbally, however, is unique to humans. This opens up vastly more extensive and transformative possibilities with respect to temporal responding (Hayes, 1992). One possibility is that this derived relational behavior allows humans to not just experience time unidirectionally like non-verbal organisms, but to also verbally construct time as a bidirectional dimension in which events can be ordered (Hughes & Barnes-Holmes, 2016). For instance, a person may temporally frame events that have not been experienced from the past (e.g., my grandparents' lives before I was born) or the future (e.g., what happens after I die), and respond to these events as though they belong to a particular sequence. Temporal relational framing is also significant as it allows individuals to frame verbally constructed past or future events and bring functions of these events to bear in the present without needing to contact them directly. For example, a person may temporally relate events such as, "You get lung cancer after you start smoking," or "Save money before you retire to avoid poverty in old age." Such patterns of framing may transform the functions of the present context and support producing alternative, perhaps more beneficial patterns of behavior. For example, the functions of smoking may be transformed such that it acquires functions of lung cancer which may make smoking less appetitive. In the second example, the functions of saving may be transformed such that it takes on functions of poverty avoidance which may make saving more appetitive. Though the degree to which responding is altered in the present is ultimately dictated by the context, temporal framing allows for the possibility to respond to a verbally-constructed future without having to experience direct contingencies (e.g., involving aversive scenarios such as lung cancer or poverty) (Bach & Moran, 2008).

Whereas a nonarbitrary temporal relational response is primarily controlled by experienced change from one event to another, arbitrary applicable temporal relational responding is primarily under the control of a contextual cue that specifies the relation. In an English-speaking socioverbal community, common stimuli likely to be used as contextual cues for temporal relational framing include words such as, "before/after," "first/last," "earlier/later," etc. An RFT account argues however that these stimuli are not unique in and of themselves but rather that any stimulus can function as a cue for temporal framing depending on the reinforcement history of the relational response. For example, someone tapping a wristwatch or even just their wrist in a particular context might function as a cue that they wish an observer to speed up what they are doing. In this particular case RFT would suggest that this gesture participates in a relational network in which the gesture means something akin to, "Pay attention to the time" which might be further elaborated as, "It is now (or soon will be) AFTER the time at which you should be finished and there are aversive consequences for not finishing on time." The person would perform the task faster to the extent that their behavior was under the control of relevant contextual cues affecting transformation of those particular functions.

Properties of Temporal Relational Framing

Temporal relational framing exhibits the same three properties as relational framing more generally. An example of mutual entailment would be being taught that June is before July and then deriving without further training that July is after June. Mutually entailed relations can be combined to allow combinatorial type derivations. For example, if a learner is taught that June is before July, and July is before August, then they can derive that June is before August and that August is after

June. Additionally, the stimulus functions of an event can be transformed based on the derivation of temporal relations between that event and others. For example, imagine that an employee is told that upcoming meeting events A and B, which are separated from each other by a number of weeks, both have to be prepared for and that event A happens before event B. Based on this temporal relation, the employee may then prioritize their preparations by allocating more of their immediate time and attention to event A than to event B. As a second example imagine that we are told that something eventful happened at a party and want to find out what happened from potential witnesses. If we learn that Person A turned up at the party at some time after Person B, then we might be more interested in talking to Person B than to Person A.

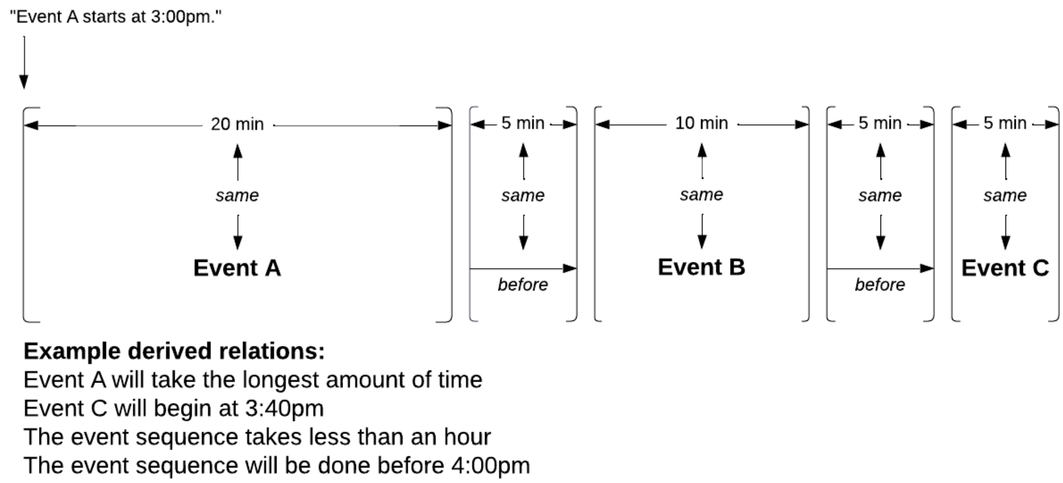
It should be noted that arbitrary temporal relations do not pertain to the properties of the stimuli or the specific events that are being related. In other words, the relations involved typically do not refer to properties of the events being related but instead to properties of the context of those events. For example, deriving that A is after B only details the relative temporal order of stimuli A and B, not any of their attributes, such as color or size. While the features of temporally related events may remain unknown in some circumstances, it is possible that the ordinal functions of those events can be transformed through a temporal relation. For instance, given a relational context that A is after B and B is after C, a new response can be made about which event happens first (event C), or last (event A) perhaps in contrast to the way an individual might have ordered those events prior to deriving this relation.

Temporal Relations and Quantification

Although temporal relations in accordance with "before" and "after" cues do not detail the physical properties of the relata, events themselves do have the nonarbitrary temporal property of extension in time. Arbitrary words used for temporal extent (e.g., minute, hour) can be related in frames of coordination with various stimulus events within a given relational network (Fig. 2.1). As such, more precise relations can be derived (Hayes, Fox, et al., 2001). Quantification can be applied to both order of events and duration of events. With ordering in time, quantification allows greater precision with respect to when events happen (e.g., if A is five minutes before B and B is five minutes before C, then the precise relations that A is at least ten minutes before C and C is at least ten minutes after A can be derived). With duration, quantification allows greater precision in terms of specifying extension in time (e.g., if A is ten minutes longer than B and B is five minutes longer than C, then we might derive that A is fifteen minutes longer than C and that C is fifteen minutes shorter than A). This verbal specification of when stimulus events begin and end allows even greater precision with respect to the temporal organization or classification of events. If a person frames both the order and duration of events, then they can make better predictions with respect to the timing of those events and their subsequent behavior in the context of those events may be more successful (see example derived relations in Fig. 1).

Figure 2.1

Example Relational Network Involving Quantification



Temporal and Other Relations

Comparison Relations

Temporal relations have occasionally been conceptualized as a particular subset of comparison relations (Dixon & Stanley, 2020). Comparison relations involve relating stimuli along a specified quantitative or qualitative dimension, which could include a temporal dimension. Temporal and other comparison relations share the feature of non-symmetry. If A is "bigger than" or "before" B, a non-symmetrical relation B is "less than" or "after" A is entailed. Temporal and comparison relations also share the feature of specificity when quantification is added to the relational context. If A is "twice the size" or "two minutes before" B, a more precise relation can be derived (Hayes, Fox, et al., 2001). However, comparison and temporal frames might be distinguished from one another in terms of a corresponding transformation of function (O'Hora & Maglieri, 2006). Transformation of function in accordance with a comparison relation may frequently involve changes to the physical response (e.g., pressing a button faster to earn a larger prize). With temporal relations, a transformation of function involves the occurrence or non-occurrence of a response (only pressing the button after the instructor says "go," and not before).

Spatial Relations

Temporal relations can be likened to spatial relations, which may also be considered a subset of comparison relations. A relationship between space and time has often been appreciated across disciplines, such as in physics (Einstein, 1905), philosophy (Grünbaum, 1974) and psychology (Piaget, 1971). Within RFT, spatial and temporal framing are skills that support a person's ability to advantageously navigate their environment in space and time. Temporal relations between events are often be represented spatially due to the abstract nature of time, often corresponding with a language's writing direction in natural contexts. In (English speaking) socioverbal communities, certain contextual cues may even be used in the case of both spatial and temporal frames. For example, "before" might indicate a stimulus closer in space, or an event that occurred earlier in time. Conceptually, it is possible a more general frame is learned earlier in acquisition prior to finer discriminations between temporal and spatial features of the context. Nonetheless, empirical work is needed on this point regarding the acquisition of both frames. Temporal and spatial frames may also be considered component relations involved in deictic framing, which RFT suggests is the basis of perspective taking (McHugh et al., 2004).

Deictic Relations

Temporal relations can also be either deictic or non-deictic. Deictic relations (I-You, Here-There, Now-Then) depend on the perspective of the person doing the relating (see e.g., McHugh et al., 2004; McHugh & Stewart, 2012). Deictic temporal relations involve relating events in accordance with contextual cues such as now-then or today-yesterday-tomorrow. A person relates events occurring at other points in time, whether past or future, relative to their current temporal perspective (e.g., Christmas was not that long ago; my birthday is X days from now). The derived response in these deictic temporal frames would change depending on the perspective. RFT-based research on deictic relations more broadly has revealed developmental patterns, and provided evidence that deictic relational frames seem relevant to perspective taking skills, and that they can be trained (Gilroy et al., 2015; McHugh et al., 2004; McHugh et al., 2009; Montoya-Rodríguez et al., 2017). Non-deictic temporal relations in contrast to their deictic counterparts do not depend on the perspective of the speaker. Events can be temporally related as before or after one another independent of the present moment perspective (e.g., university is after high school; Toy Story 1 was released before Toy Story 2). Indeed, a similar distinction between deictic and non-deictic temporal responding has been noted outside of the RFT literature (McCormack & Hoerl, 1999) and some theorists have suggested that learning to adopt temporal perspectives other than the here-and-now is an important aspect of a mature understanding of time (Cromer, 1971; McCormack & Hoerl, 2017; Weist, 1989).

Causal Relations

Another issue concerning temporal relations is how they relate to causal or conditional relations. Causal/conditional relations are similar to temporal relations in that both specify temporal ordering of events. However, whereas a temporal relation describes events as simply occurring in succession, a causal or conditional relation additionally specifies a contingent relationship between events (e.g., if A, then B; A causes B, B is an effect of A) (Biglan & Barnes-Holmes, 2015; Carmelo Visdómine-Lozano, 2015; Hayes, Fox, et al., 2001). Hayes, Fox, et al. (2001) suggest that causality does not have a physical dimension, as "causes" of events may be based on any number of characteristics such as contiguity, manipulability, beliefs, etc. Furthermore, in the socioverbal community, contextual cues typically used for each of these frames appear to overlap somewhat flexibly, at least within the English language. For example, "*First* A, *then* B" may refer to a simple sequence of events, or refer to a behavioral contingency, or even a cause-effect relationship. It is necessary to consider the functional properties of the verbal relation on the listener in these circumstances rather than only the topography of the contextual cues. For the purposes of the present chapter because of the functional overlap between the two varieties of relations, causal/conditional relations will be treated as a special subcategory of temporal relations and hence will include the former in many of the analyses and examples. However, additional research is needed to explore to what degree temporal and conditional or causal relations should be considered functionally similar to or distinct from each other (Hughes & Barnes-Holmes, 2016).

Acquisition of Temporal Frames

With respect to the acquisition of temporal relational framing, this repertoire is learned similar to other frames—through a history of multiple exemplar training (MET). Some authors have suggested that while temporal relations are similar to comparative and spatial relations (i.e., all involve relating events along a specified dimension), temporal frames are acquired later than either comparative or spatial relations, possibly due to the more abstract nature of ordering events along a temporal dimension (Hayes, Fox, et al., 2001). Some support in this respect can be found in research on deictic framing. McHugh and colleagues (2004) showed that spatial (here/there) relations appeared before temporal (now/then) relations, while other studies in this area point also toward temporal relations being more difficult to acquire than spatial (Gore et al., 2010; Weil et al., 2011). Deictic frame training protocols have generally recommended that temporal relations be trained after both interpersonal (I/you) and spatial (here/there) relations (McHugh et al., 2009). More recent RFT research examining the development of relational framing in children between 3-7 years across multiple frames and at different levels of complexity indicated that temporal frames appeared to be the last to emerge (Kirsten & Stewart, 2022). More research is needed however to determine the optimal point for introducing temporal relations in a relational frame training sequence.

Temporal Relations and Rules

Temporal relations are also considered important in rules and rule-following. Skinner (1969) introduced the term rule-governed behavior to describe behavior that differs from contingency-shaped behavior. Whereas contingency-shaped behavior occurs due to a history of direct contact with contingencies, rule-governed behavior has not contacted the contingencies and is instead under control of "rules;" which he defined as verbal stimuli that *specify* contingencies. From an RFT view, verbal stimuli (e.g., rules) acquire their specifying properties via derived stimulus relations.

Rule-governed behavior very frequently but not invariably involves responding in accordance with derived relational networks with both equivalence and temporal relations (Harte et al., 2020)[5]. Equivalence relations are established between the words in the rule and the objects or events they refer to. The temporal contextual cues specify the order in which events or responses are to occur

[5] Temporal relations may often be involved in rule-following, but this may not always be the case. Some simple rules might not specify a temporal relation (e.g., "do this" does not include a temporal contextual cue). Temporal relations are however arguably involved in any rules that specify a contingency since such rules tend to involve cues such as "if" and "then."

and/or the possible contingent relation between them (Figure 2.2). Derived relational responding in accordance with the rule may transform the function of events and actions within a particular context, and thereby introduce a new source of influence on behavior (Hayes & Hayes, 1989). For example, consider a parent introducing a rule to their young child within the context of a new game, “If you collect three tokens before the other player does, then you win the game.” In this example, the child must engage in a number of relational framing responses for this statement to be understood and function as a rule, including frames of equivalence (between the words and the actual events or objects), and temporal frames (contextual cues “if” and “then” specify a behavioral contingency and the contextual cue “before” specifies a temporal order of events).

Figure 2.2

Example Relations Involved in a Rule

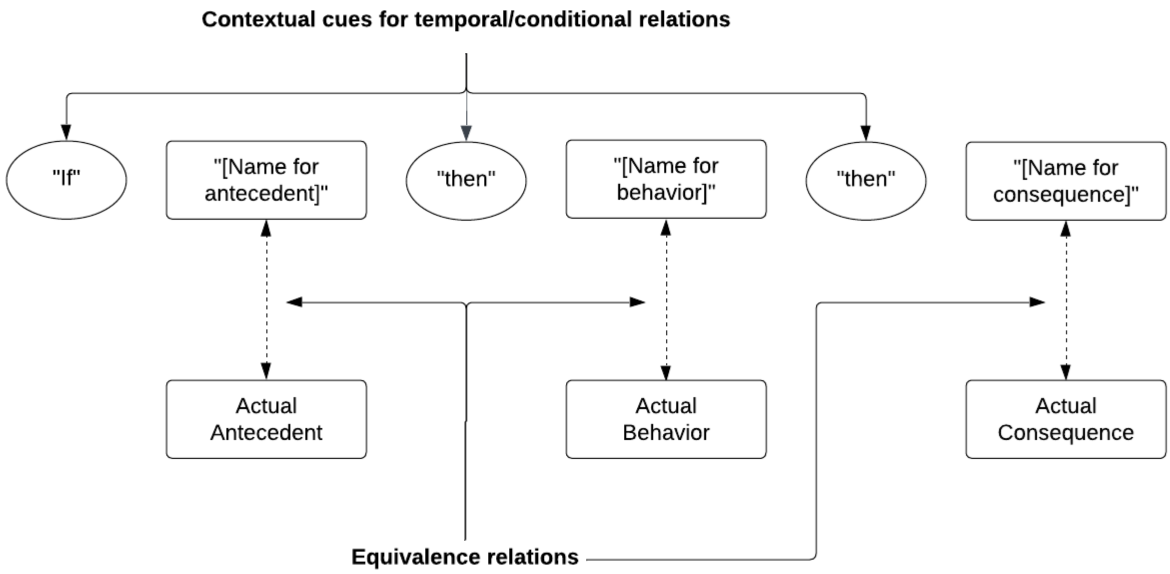


Figure adapted from Tarbox, Campbell, et al. (2020)

If the child has a repertoire involving these frames, this can provide a source of behavioral regulation for the child as they can detect whether their behavior and actual events in the environment coordinate with the events described in the rule. There is already relevant empirical evidence on rule-following thus conceptualized. Some research with children with disabilities has shown that basic rule-following repertoires can be established and generalized to novel rules by teaching causal (“if/then”) relations between antecedents and behaviors (Tarbox et al., 2011) and between behaviors and consequences (Wymer et al., 2016). Additional factors influence whether or not a rule is actually followed but without such a relational framing repertoire, the rule could be neither understood nor followed (Stewart & Roche, 2013; Tarbox, Campbell, et al., 2020). These studies further support the key role of temporal/causal framing in rule-governed behavior, but much additional research is needed. For example, the children involved in these studies had already acquired the key framing repertoires needed and thus the job of the researchers was essentially to teach exemplars involving the combination of these frames. However, the history and training needed to establish key frames such as temporal/causal frames themselves in very young children and children with disabilities needs to be explored in detail as well as the potential range of behaviors that the acquisition of such frames facilitates.

RFT–Based Empirical Studies on Temporal Relations

While research on temporal relational framing is as yet limited, there have been a number of studies conducted. Temporal frames were first examined in studies investigating rule-based (or instructional) control. O'Hora et al. (2004) trained and tested 12 undergraduates on a computer-based relational responding protocol that involved "before/after" and "same/different" relations across two experiments. In the case of the temporal relations, two arbitrary symbols were trained as contextual cues for "before" and "after" by reinforcing the choice of a "relational statement" involving one or the other cue as a description of a previously seen nonarbitrary sequence of shapes. Once responding in accordance with contextual cues for "before/after" and "same/different" relations was acquired, participants were then given a test for instructional control via a task in which they had to press computer keys in particular sequences that were specified by arbitrary relational networks involving all four cues. Sequenced responding was observed to be controlled by the relational cues in 8 of 12 participants as they met performance criteria on the tests for instructional control. These performances thereby demonstrated transformation of an ordering function in accordance with the temporal contextual cues. In the second experiment, each of the participants who reached criterion on a test for instructional control additionally showed generalization of responding to novel stimulus sets. Accordingly, these results provided preliminary evidence both that derived temporal relational responding could be induced in a laboratory setting and that it could contribute to a laboratory-based model of rule-governed behavior.

Two subsequent studies expanded on these findings by using the O'Hora (2004) relational testing and training protocol to correlate derived relational responding performance with scores on a standardized measure of cognitive abilities. O'Hora et al. (2005) trained and tested seventy-five undergraduate students on a protocol similar to the one employed in O'Hora (2004). Once mastery criteria were reached, participants completed the vocabulary, arithmetic, and digit-symbol coding subtests of the Weschler Adult Intelligence Scale (WAIS-III). Results showed that mastery performance on the relational responding task was a significant predictor for performance on both vocabulary and arithmetic subtests. A follow-up study by O'Hora et al. (2008) examined whether performance on a similar temporal relations task predicted performance on all four indices of the WAIS-III in eighty-one undergraduate students. Results showed significant correlations between percentage of correct trials on the temporal relations task and scores on the Verbal Comprehension, and Perceptual Organization indices. Significant correlations were also found between relational responding and each subtest of the Verbal Comprehension index.

A number of more recent studies have investigated accuracy and speed of responding to "before" and "after" contextual cues in the context of nonarbitrary ordering tasks. While this work was centered ultimately on a nonarbitrary ordering task, the findings are likely relevant also with respect to temporal framing. Hyland et al. (2012) delivered a training/testing procedure with "before" and "after" cues to university students. In Experiment 1 participants observed a sequence of two physical shapes (e.g., a square followed by a circle) on a computer screen and were then shown an array of four physical shapes (square, circle, triangle, and cross) on both the left and right side of the screen. Following this, either the word "before" or "after" was presented in the middle of the screen between the two arrays of shapes and participants were required to select the shape on both the left and right of the cue word that would correspond to the order in which the two original shapes had appeared. For example, if a circle appeared following a square and the word "before" was then shown between the two shape arrays, then the participant would have to select the square on the left and the circle on the right. Results showed that participants responded significantly faster on "before" cue trials than on "after" cue trials and a second experiment replicated this result using abstract as opposed to familiar stimuli. A subsequent study by Hyland et al. (2014) further examined speed and accuracy with temporal contextual cues using a slightly different methodology. On each trial participants were shown a relational statement involving physical shapes with either the cue "before" or "after" between them (e.g., circle BEFORE triangle). After viewing the statement, participants were given an array of physical shapes and asked to select the shapes in the order specified by the relational statement (e.g., choosing a circle and then a triangle). Results revealed no difference in accuracy between "before" and "after" trials, but response speeds were again significantly faster for "before" compared to "after" trials.

McGreal et al. (2016) extended these findings by comparing performance on a temporal relations task between younger (M = 19 years) and older (M = 61 years) participants. A go/no-go task was used in which each participant first observed a sequence of images on a computer screen (A…B) and was then presented with a temporal relational statement involving the two stimuli involved (A BEFORE B; B BEFORE A; A AFTER B; B AFTER A). If the relational statement accurately described the sequence shown, participants had to provide a key-pressing response whereas if the statement did not describe the sequence accurately, they were to make no response. Results showed that the older participants demonstrated slower response speeds compared to the younger participants. Across both groups however, participants showed less accurate and slower responses to statements involving the "after" cue (e.g., A AFTER B) than to statements involving the "before" cue (e.g., A BEFORE B).

Overall, these findings suggest that when asked to engage in nonarbitrary temporal relational responding (i.e., identifying the temporal order of events) under the control of temporal relational cues, respondents are faster to respond given a "before" cue than an "after" cue. A subsequent paper by Brassil and colleagues (2019) offered a possible explanation for this finding. Even in arbitrary relational statements, a nonarbitrary temporal relation is in effect. Consider an arbitrary relational statement, "A before B." As an individual either hears that statement spoken or reads the statement, they are responding to a nonarbitrary relation. In other words, the arbitrary relata in the statement itself (i.e., "A" and "B") are being experienced sequentially in time. It is possible that subsequent correspondence or non-correspondence between the nonarbitrary order of actual events and the order of the names for those events as they appear in the relational statement (i.e., the order in which the names are heard or read) may influence response latency. For example, if an arbitrary relational statement "B after A" is an accurate description of an event sequence (i.e., A happens and then B happens) there is non-correspondence between the nonarbitrary relationship between the spoken or read stimuli B and A in the statement and the nonarbitrary relationship between the physical events described by that statement, which may affect response latency. Brassil et al. (2019) demonstrated that this increased response latency with reversed relational statements can occur not only with the temporal cues, "before/after," but also with cues for other relations. More specifically they showed that it could occur for the comparative cues "bigger/smaller," supporting previous findings that patterns of relational responding share similar characteristics (Steele & Hayes, 1991). Nevertheless, the fact that this effect is caused by nonarbitrary temporal relations suggests the possibility that it might impinge on arbitrary temporal relational responding, particularly when individuals are first learning this repertoire. For example, it has been shown in previous research that nonarbitrary relational responding can supersede arbitrarily applicable relational responding on tasks involving competing sources of stimulus control (Kenny, Barnes-Holmes, et al., 2014). Competition between nonarbitrary and arbitrary temporal relational stimulus control, especially in a developmental context, should be a focus of future research.

Despite the growing research attention devoted to derived relational responding more generally, research on temporal relations has presently only been conducted with typically developing adults with already strong verbal repertoires. Questions remain on which types of relational skills and other prerequisites are needed to establish temporal relational responding, and which types of training methods are effective with children and neurodiverse populations. Accordingly, a key focus of future RFT research should be to examine the acquisition of temporal relational framing in young children and to investigate in addition how this repertoire can facilitate responding to time as an abstract verbal concept.

Research on Temporal Skill Sets and RFT Application

Derived (arbitrarily applicable) relations, and particularly temporal relations, allow the derivation of rules about sequences of events and this changes how humans respond to their environment (O'Hora et al., 2004; 2014; Stewart & Roche, 2013). These acquired relational skills are critical to human functioning at both individual and societal levels. As such, it behooves both basic and applied researchers to provide a functional understanding of how these repertoires are acquired and how they can be trained when absent or deficient and RFT is well-equipped to provide this. In the following section, we offer a range of important repertoires in humans that require the capacity for abstract temporal responding and hence in RFT terms require arbitrarily applicable temporal relational responding. These repertoires include sequencing, timing, use of conventional time systems, self-control, planning, and time management. This list of repertoires is not intended to be exhaustive but rather to draw the reader's attention to key areas of investigation in which derived relations may be relevant to a human understanding of time. We argue that an RFT paradigm offers both theoretical and applied implications for future research into the human understanding of time in these areas. For each area, we will first provide a brief overview of relevant literature and will then offer recommendations that exemplify how to possibly apply RFT to the topic.

Temporal Sequencing Skills

Summary

Temporal sequencing or event ordering refers to the ability to order events according to a temporal dimension. This skill is important to organizing events, scheduling, and sharing about the past or future. Most research in this area has stemmed from cognitive developmental or psycholinguistic frameworks (Zhang & Hudson, 2018). Research with children has evidenced improvements in temporal sequencing as language and cognitive abilities improve throughout development (McCormack, 2015; McCormack & Hanley, 2011). A variety of methods have been used to evaluate this skill such as picture sequencing tasks, answering questions about the temporal event order, and acting out sequences in a specific order (Amidon & Carey, 1972; McColgan & McCormack, 2008; Moore et al., 2014; Pyykkönen & Järvikivi, 2012). Age-related performance in children with these tasks appears sensitive to particular aspects of the context that are emphasized (Bauer & Mandler, 1989; Clark, 1971; Friedman, 1990). The research presented below is organized by age-related performance with temporal ordering tasks that have focused on different aspects of the context.

Ordering Events Forward and Backward. In sequencing tasks, events can be ordered going forward (e.g., starting with the first event, and sequencing the events that come after) or backward (e.g., starting with the last event, and sequencing the events that come before). Research has shown forward ordering to be easier for young children than backward ordering. Fivush and Mandler (1985) assessed performance in 4-6-year-olds on picture sequencing with familiar events (e.g., going to McDonald's) and unfamiliar events (e.g., going parachute jumping) and found that overall performance improved with age. Across ages and materials, children performed best with familiar events in forward order followed by unfamiliar events in forward order, familiar events in backward order, and finally unfamiliar events in backward order. By 5 years, children may sequence pictures of daily events forward and backward, and judge forward order from multiple points of reference (i.e., ordering events when beginning at different points in the sequence) (Friedman, 1990). Other research has shown that it was not until mid-adolescence that children accurately judged the backward order of days and months from multiple reference points (Friedman, 1986). More recently, Moore et al. (2014) observed that in children aged 5-10 years, backward ordering daily events was more difficult than forward ordering and relative ordering (a sample picture is given and selecting which picture comes before or next in the sequence).

Ordering Invariant and Variant Events. The relative connection between events as they occur in the environment (i.e., whether one event tends to naturally lead to another event or not) may also affect performance on temporal sequencing tasks. Invariant events refer to events that always occur in this order in the real world (e.g., grocery shopping prior to leaving with grocery bags). Variant events are arbitrary sequences that can occur in any order (playing with toys before or after eating a snack). Carni and French (1984) assessed preschoolers' comprehension of temporal words by using pictures depicting a story of either invariant or variant sequences and asking them questions about what happened before or after particular events. Results indicated that 3-year-olds were able to answer "before" and "after" questions with only invariant sequences while 4-year-olds could answer both types of questions accurately. Some research has also examined recall of temporal order in even younger children. Bauer and Mandler (1989) found that 1- to 2-year-olds performed better with causal sequences on immediate and deferred imitation tasks (i.e., reproduce action-sequences in the correct order) compared to arbitrary sequences.

Ordering Past and Future Events. Other research has investigated temporal order in terms of past or future remoteness from the present. Sequencing future events has been observed to be more challenging for children than past events. In a study on children's reporting of past events, Friedman (1991) presented two unrelated novel events, with the second event taking place six weeks after the first. Children were subsequently shown cards about the events one week later and asked questions about them. Four-year-olds were able to discriminate which event was more or less recent but could not specify their temporal location with conventional time units (e.g., estimating the month or approximate day of occurrence). Between 6-8 years, children showed increased accuracy with reporting on when the past events occurred with reference to calendar time. This finding with past events has been extended in other situations and with varying approaches, such as using a spatial timeline (Friedman et al., 1995; Friedman & Kemp, 1998). Friedman (2000, 2002) later showed that children's discrimination of the relative temporal distances of future events also improves with age. In the Friedman (2000) study, children between 4-10 years were tested on future event ordering by answering questions about how far into the future certain events would occur or by pointing to parts of a spatial timeline. In contrast to performance with past events, 4-year-olds failed to accurately discriminate future events as coming "soon" or "in a long time." Between 5-7 years, children could discriminate between events in the near or more distant future, and between 7-10 years, children gradually improved in using conventional time units to reference events (e.g., estimating how many months from now).

McCormack and Hanley (2011) extended these findings by directly comparing performance on a past/future order task in 4-5-year-olds. Children were shown two pictures of familiar past or future holidays and asked questions about their temporal order relative to the present (e.g., “Which happened a short/long time ago?” or “Which will happen a short/long time from now?”). Both age groups performed well with “past” questions but only 5-year-olds answered “future” questions with a similar level of accuracy. Performance on the past and future reasoning tasks did not correlate with each other, however performance on both tasks correlated with comprehension of the terms “before” and “after.”

Order-of Mention and Event Order. Performance with temporal order may also be influenced by the position of temporal terms like “before” and “after” in sentences. A description or instruction about an event sequence can be stated in multiple ways (Table 2.1).

Table 2.1

Example Arrangements of Sentences Describing a Temporal Sequence

Event order	Order of mention
Ate dinner…watched TV	1) “She ate dinner before she watched TV.” 2) “After she ate dinner, she watched TV.” 3) “Before she watched TV, she ate dinner.” 4) “She watched TV after she ate dinner.”

Note. Event order refers to the actual temporal sequence of events as they occur. Order of mention refers to how that series of events is verbally described.

In sentences 1 and 2, event order and the order-of-mention match, whereas in sentences 3 and 4 the event order and order-of-mention do not match. Experimental methods have compared performance in children across each sentence type by either showing a modeled sequence of events and asking participants questions about the event order, or by presenting a temporal instruction and having participants perform sequenced actions. Multiple studies have found that young children perform better with matching sentences (sentences 1 and 2 in Table 2.1) compared to non-matching sentences (sentences 3 and 4 in Table 2.1) (Blything et al., 2015; Clark, 1971; Keller-Cohen, 1987; McCormack & Hanley, 2011; Trosborg, 1982). Errors in comprehension of these terms have been demonstrated up to early adolescence depending on their sentence placement. Pyykkönen and Järvikivi (2012) assessed 8-12-year-olds using a written questionnaire that included these four sentence varieties. Participants were asked to answer comprehension questions about the order of the events referenced in the question. Results showed that the children’s accuracy was affected by the position of “before” and “after” within the sentences. While performance generally increased with age, even the 12-year-olds did not perform to the levels of accuracy that an adult comparison group demonstrated.

Ordering Events across Languages. The way in which children order events may also depend on their learning histories in their respective socioverbal communities. Some research has investigated this by examining how time is represented across different languages. Boroditsky (2001) suggested that since "time" is not observable, it is most often specified in languages using spatial metaphors (e.g., whether time moves forward/backward, left/right, up/down, past us, or through us). Since these terms are used to represent the unobservable aspect of time, there may then be variability across languages in how time is expressed. Boroditsky (2001) showed that English-speakers often used horizontally oriented metaphors to talk about time (e.g., the past is *behind* us, the future is *ahead* of us), while Mandarin speakers additionally used vertically oriented metaphors for representing time (events move from *up* to *down*). Temporal order also tends to be spatially represented in accordance with writing direction. Whereas the order of events is conventionally arranged left-to-right in languages such as English, languages that read right-to-left (e.g., Arabic) tend to spatially order events right-to-left (Fuhrman & Boroditsky, 2010). Moreover, Boroditsky and Gaby (2010) observed that an Australian aboriginal community ordered pictures east-to-west instead of a relative order like left-to-right or toward/away from the body on a sequencing task. In other words, the direction they arranged the pictures changed depending on which direction they were seated so that the pictures consistently progressed from east-to-west.

Further research by Hendricks and Boroditsky (2017) examined the effects of learning new relational metaphors on representations of temporal event order. Undergraduate English-speaking students were trained in new ways to talk about time. One group was trained that earlier events were "down" (e.g., Thursday is *lower than* Friday) whereas another group were trained that earlier events were "up" (e.g., breakfast is *above* dinner). Both groups subsequently completed a space-time implicit-association task. Results showed that with sufficient exposure and response training with a new representation of time, participant responses were quicker with trials on the implicit-association test that were congruent with the representation of time that they learned during training. The authors noted that differences between the two groups were similar to those observed in cross-cultural studies of time representation. These findings show how language and social context may influence the way in which a person uses language to represent time.

RFT Extension

A challenge raised in the cognitive developmental literature is that it is difficult to fully examine the role of language acquisition in the development of time concepts in children with the methods commonly used. As language is necessary to describe the more abstract nature of time, methodologies have necessarily relied on tasks involving language (McCormack & Hoerl, 2017; Zhang & Hudson, 2018). Nelson (1996a, 2007a, 2007b) has argued that children learn how to temporally organize events and reference themselves or others in the past and future through verbal interactions (e.g., sharing of past and future experiences, direct instruction of conventional time systems). However, cognitive developmental and psycholinguistic research has largely been descriptive and has deemphasized environmental conditions that give rise to the acquisition of these skills in children.

Mainstream literature has indicated that as children age, the way in which they orient themselves in time tends to shift and become increasingly abstract (McCormack & Hoerl, 2017). From an RFT perspective, we suggest that this happens based on the gradual acquisition of temporal relational responding. In the younger years, children temporally relate events at the nonarbitrary level (i.e., the change from one event to another). Across a wide variety of exemplars, contextual cues used with these nonarbitrary events come to control arbitrarily applicable temporal relational responding. The acquisition of AARR allows for a person to increasingly experience time in a more verbal or abstract sense. As such, a child's ability to temporally order events might be approached by examining temporal relational responding at both nonarbitrary and arbitrary levels.

This critically important RFT-based distinction between nonarbitrary and arbitrarily applicable temporal relations can be used to analyze and understand findings from cognitive developmental research. Studies in which children observe a sequence of actions and respond to their temporal order (e.g., Blything et al., 2015; McCormack & Hanley, 2011) are focused on temporal NARR as the relational response is controlled by the nonarbitrary feature of sequential change. Such tasks assess a simpler, more concrete level of responding than tasks targeting temporal AARR. With temporal AARR, no sequence of actual physical events need be involved as the relational response is instead primarily under the control of particular (temporal) contextual cues. For example, Pyykkönen and Järvikivi (2012) used a written questionnaire to assess "before" and "after" such that children had to temporally order events based on the presence of the temporal cue in the sentence. The researchers reported challenges in children even up to the age of 12 years. From an RFT perspective, this finding makes sense given the more abstract nature of arbitrarily applicable relations, as well as the fact that time is a relatively verbally constructed aspect of experience (see overview of temporal relations section).

This can make sense of other findings, such as data indicating that children's understanding of relations between future events is more difficult than with past events (Friedman, 2000, 2002; Friedman & Kemp, 1998). Relating future events involves increased arbitrariness given the fact that past events can be directly experienced whereas future ones are always necessarily hypothetical. Indeed, McCormack and Hanley (2011) provided a similar, yet cognitively oriented reason for their results showing that future reasoning was more difficult for children than reasoning about past events. The authors suggest that while children need to understand before-after sequences about past events, they do not need to construct the sequence and can recall the temporal order of events. The same approach for future events does not work however, and they must construct novel temporal sequences. Bringing an RFT approach to such findings might allow novel insights and exploration with a more practical educational orientation.

Future RFT research can take multiple directions to address present limitations in the literature on children's understanding of temporal order. One direction includes examining age-related performance on increasingly difficult tasks of temporal relational responding (e.g., from nonarbitrary to arbitrary relations, from mutual to combinatorial entailment). Changes in children's temporal understanding have been observed between the ages of 3-5 years and some accounts have proposed that a critical shift in how children think about time occurs within this age range (Atance & O'Neill, 2005; Busby Grant & Suddendorf, 2010, 2011; McCormack & Hanley, 2011; McCormack & Hoerl, 1999; Perner 2001; Weist, 1989). RFT research could investigate whether the acquisition of temporal or other patterns of relational framing corresponds with improvements on temporal sequencing tasks during these ages. Similarly, researchers might consider age-related performance with temporal deictic relations ("now/then") and compare this to performance on tasks involving the relative distance of past/future events (e.g., Friedman, 2000). Exploring age-related performance with temporal relational responding at increasing levels of complexity throughout childhood may offer new insights into whether derived relational skills are related to performance on other measures of temporal understanding.

A second direction is to establish effective training methods to improve temporal relational responding when absent or deficient. While current research has revealed age-related and context-specific performance differences on a variety of tasks of temporal understanding (McCormack & Hanley, 2011; Moore et al., 2014), there is currently minimal research evaluating how these skills can be trained. RFT suggests that temporal frames can be trained using MET, as has been successfully accomplished with various other relational patterns (Berens & Hayes, 2007; Mulhern et al., 2018). In one version of MET, a specific relational response might be trained using a particular stimulus set and once established, a novel stimulus set might be used to test for generalization. If the participant fails the generalization probe, they can then be trained to mastery on the failed test set before being tested again for generalization on another novel set. This testing-training approach is repeated until sufficient exemplars have been used to establish the generalized relational response.

When conducting MET, nonarbitrary temporal relations may first be trained if not already present in the learner's repertoire by presenting multiple exemplars of stimulus sequences (e.g., stimulus A presented first followed by stimulus B). The stimuli are rotated across trials and the learner is asked which stimulus came before or after the other one. During training, correct responses are reinforced and incorrect responses receive error correction until the goal criterion is met. Once nonarbitrary temporal relational responding is demonstrated, the next phase is to transfer contextual control to arbitrary stimuli. To establish arbitrarily applicable temporal relations, a learner may be presented and trained with two or more stimuli simultaneously with a contextual cue indicating a temporal relation between stimuli (e.g., shown an image that reads A is before B, B is before C) while being tested for derivation (e.g., "Is B after A?", "Is C before A?", etc.). At this level, an instructor may consider not presenting the physical stimuli sequentially. This would introduce a nonarbitrary temporal relation which may interfere with establishing appropriate stimulus control of the relational response under the "before" and "after" arbitrary contextual cues. Testing for a transformation of function in accordance with a temporal relation might be done in a variety of ways. For example, a game context might be employed in which various action functions are first differentially trained to a set of stimuli (e.g., blue card-raise hand, red card-clap, yellow card-wave). When presented with the stimuli interspersed with temporal contextual cues (e.g., yellow after red after blue), transformation of function is shown if the child is able to perform the actions in the order specified (i.e., for this example a correct response occurs if the learner first raises their hand, then claps, then waves).

Future RFT research could also investigate whether differences in the types of stimuli used as relata support or hinder the acquisition of deriving temporal relations. A few studies with equivalence relations have shown that using familiar stimuli may be more efficient and lead to higher likelihood of derived responses occurring compared to unfamiliar stimuli (Fields et al., 2012; Ming et al., 2015; J. O'Connor et al., 2017). Considering that a temporal dimension is inherently more abstract than other stimulus dimensions (e.g., physically perceptible features like color or size), this may be particularly relevant to temporal frames. If using familiar stimuli, an additional consideration might be whether derived temporal relations with "before/after" cues are more easily demonstrated with invariant events (e.g., go to bed, fall asleep) compared to variant events (e.g., play the piano, watch TV). Sequencing invariant events appears to be easier than variant events in early childhood (Carni & French, 1984). It is possible that this finding may be relevant to training temporal relations. Comparing rates of acquisition of AARR with differing stimuli may help point towards potentially more efficient training regimens. Examining potential effects of using invariant versus variant stimulus events may help not just in facilitation of training, but also in examining the distinct trajectory of causal framing as a possible subset of temporal framing.

Along these lines, future research with temporal frames may be directed toward how this repertoire can be supported by, combined with, or augment other relational skills. For example, do derived non-deictic temporal relations precede or support the acquisition of deictic temporal relations, or vice versa? In a series of studies, Kent et al. (2017) directly compared relational training sequences for the frames of coordination, distinction, opposition, and comparison, wherein the order of training for opposition and comparison frames was manipulated. Results provided preliminary evidence that training the relation of opposition before comparison resulted in faster acquisition of comparison relations. Similar research might extend this work by including temporal and deictic relations. Further, given the similarity between temporal and comparison relations, perhaps training the latter to a high strength might boost learning of the former.

Finally, research questions with temporal contextual cues could be explored in light of the findings from other psychological approaches. For instance, some research has found better performance with the term "before" compared to "after" in children (Table 1; Blything et al., 2015; Clark, 1971). RFT research might investigate whether children show differences in performance with one particular contextual cue (e.g., "before") compared to another (e.g., "after") on relational responding tasks. Research might examine whether training temporal AARR is best facilitated by training one cue, the other, or both concurrently. Research on temporal relations with adults has shown faster responses with "before" cues compared to "after" but no work has yet been done with children (Hyland et al., 2012, 2014; McGreal et al., 2016). Further, linguistic studies have shown that the placement of "before" or "after" in a sentence can influence comprehension and subsequent demonstration of sequenced actions (Keller-Cohen, 1987; Trosborg, 1982). An RFT account might suggest that one interpretation of this finding is that a nonarbitrary temporal relation (i.e., the order in which each event is heard spoken aloud) is interfering with the arbitrarily applicable relation (i.e., how the events are to be related based on the contextual cue). This could be examined in the context of rule-governed behavior such as: how does the placement of a contextual cue in a sentence influence rule-understanding and in-turn, rule-following? Tasks that require participants to act-out sequences of actions given a novel sentence with "before" or "after" (e.g., Clark, 1971) share similarity to demonstrations of rule-based control and a transformation of ordering function. RFT research could examine how the arrangement of temporal contextual cues in relational networks might influence rule-following behavior.

Human Timing Skills

Summary

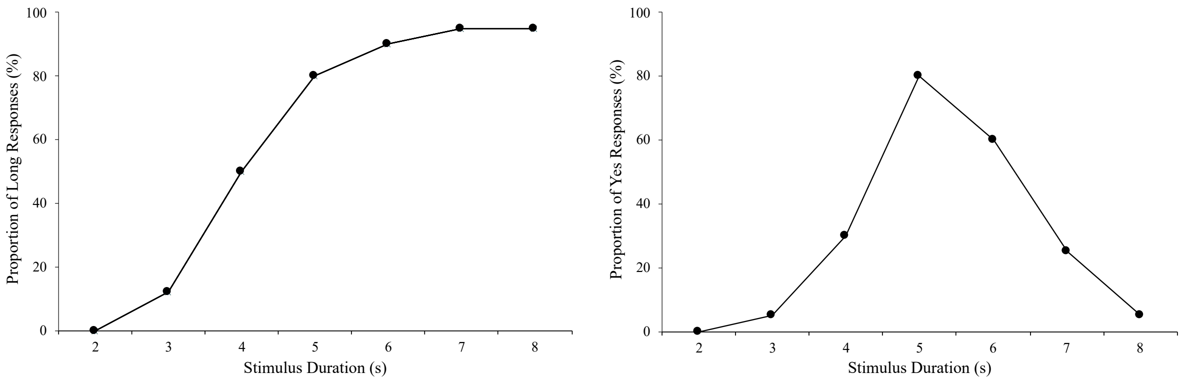
A second key area of investigation is interval timing, which refers to the ability to accurately discriminate the duration of stimulus events. Discriminating how long events last is important to predicting the timing of events, such as engaging in a behavior at the "right time" or waiting during periods of delay (Casassus et al., 2019). Research on timing has often examined seconds to minutes intervals, though it may also extended to shorter and longer durations (Droit-Volet & Meck, 2007).

Historically, resistance to control by simple interval schedules of reinforcement as children age (e.g., see Bentall et al., 1985; Droit et al., 1990) presented a challenge with using conditioning procedures to assess timing in children and alternative paradigms were subsequently used to explore this phenomenon (Droit-Volet, 2011). At present, the predominant approach to timing within psychology is Scalar Expectancy Theory (SET). SET is based on an information-processing model that suggests that organisms have an internal clock system that is used for making temporal discriminations. The scalar property of the theory is represented as an organism's estimate of an interval's duration is respective to the interval's actual length. That is to say, durations that are longer (e.g., 100s) are likelier to have more variability of response than shorter durations (e.g., 10s; Church, 1984; McCormack, 2015). Duration discrimination has been found to fit Weber's Law and multiple studies have demonstrated that this scalar property of timing is observed in both non-humans and humans (Brannon et al., 2007; Gibbon, 1977; Wearden & Lejeune, 2008). Although SET has been the predominant model in duration judgment research, various alternative models of timing have also been presented not involving an internal clock, such as the behavioral theory of timing and learning to time model (Dragoi et al., 2003; Killeen & Fetterman, 1988; Machado, 1997; Staddon & Higa, 1999; Wackermann & Ehm, 2006)[6].

Research suggests that young children, including infants, may accurately discriminate the duration of events. Multiple studies with infants have demonstrated that duration discrimination is ratio dependent rather than being based on absolute durations and that discrimination improves with age. Using a visual habituation procedure, vanMarle and Wynn (2006) showed that 6-month-old infants can discriminate between durations that differ at a 1:2 ratio (e.g., 0.5s vs 1s) but not at a 2:3 ratio (e.g., 0.67s vs 1s). Brannon et al. (2007) replicated this finding and additionally found that 10-month-olds could discriminate at a 2:3 ratio but not at a 3:4 ratio.

Figure 2.3

Hypothetical Temporal Bisection and Temporal Generalization Graphs



Note. The left-side graph displays hypothetical data on a temporal bisection task. The right-side graph displays hypothetical data on a temporal generalization task.

With children, two major research methods have often been used to examine timing skills: the temporal bisection task and temporal generalization task. In a temporal bisection task, participants are given two sample durations—a "short" duration and a "long" duration (e.g., a 500ms sound and a 1.0s sound). Participants are asked to categorize subsequently presented comparison durations that are either equal to one of the two samples or are in between them in terms of duration. A bisection curve is then constructed by graphing the proportion of "long" responses relative to the sample duration, with steeper bisection curves indicating finer temporal discriminations (Figure 2.3). In a temporal generalization task, participants are given a sample duration (e.g., 500ms) followed by comparison durations (e.g., 200ms, 800ms, etc.). Participants are then asked to judge (by responding yes or no) whether the comparison duration matched the sample duration or not. Generalization gradients are

[6] An analysis of these different models is beyond the scope of this chapter. For this interested reader, see Allman et al. (2014) for a review on the internal clock model. For arguments against an internal clock, see Eckard and Lattal (2019). See Machado et al. (2009) for a comparison between SET and the learning to time model.

constructed which represent the proportion of "yes" responses, with steeper generalization gradients again representing finer temporal discriminations (Figure 2.3). Research utilizing these approaches with children have shown developmental differences across both tasks. On the temporal bisection task, 8-year-olds have shown higher temporal sensitivity compared to 3- and 5-year-olds (Droit-Volet & Wearden, 2001). Similarly, on the temporal generalization task, 8-year-olds have produced finer temporal discriminations compared to 3- and 5-year-olds (Droit-Volet, Clement, & Wearden, 2001; McCormack et al., 1999).

A few other methods have also been used to assess children's duration judgments. These tasks include verbal estimation (e.g., "tell me how many seconds that was"), production (e.g., "Say 'start' and then 'stop' when 1 minute has passed"), and reproduction (e.g., a 10s sound clip is played, and the child is told to "press this button for the same amount of time"). In a meta-analysis by Block and colleagues (1999), age-related differences were found between children (7-12 years), adolescents, and adults with these methods. Results showed that children made larger verbal estimations, comparable productions, and shorter reproductions compared to adolescents and adults. Additionally, the interindividual variability in duration estimations decreased with age regardless of the type of duration task.

Language and verbal understanding typically play a central role in studies of duration estimation, predominantly in the form of instructions. A distinction has been made between implicit (i.e., prospective) and explicit (i.e., retrospective) timing tasks. Wherein the former involves a person being unaware of processing the time during the interval, the latter requires a person to attend to and be aware that they need to time an event as they provide an overt estimate of the duration (Coull & Nobre, 2008; Droit-Volet, 2013; Zelaznik et al., 2002). Some research has found differing developmental patterns with implicit and explicit timing by comparing performance in adults and children of 5 and 8 years. Whereas implicit timing emerges early and may not vary with age, explicit timing emerges around the age of 3 years and does improve with age alongside the development of language and cognitive skills (Droit-Volet & Coull, 2016).

It has also been noted that temporal instructions given by adults are important to children's temporal responding before they begin to follow their own rules about time (Droit-Volet, 2013). In a relevant study, Pouthas and colleagues (1990) tested 18 children aged 4.5, 7, and 11 years on a timing task in which reinforcement was contingent on a button press duration (5s). Participants were also asked questions about the contingency. Accurate responses by 11-years-old closely matched their verbalized strategies (e.g., counting the interval), while accurate responses of the two younger age groups were not coherent with their verbalizations (i.e., descriptions of the temporal aspects of the contingency were mostly absent). Droit-Volet (2013) highlighted a possible shift towards rule-control when referencing a u-shaped developmental trajectory seen with temporally-regulated behavior in experiments using FI schedules of reinforcement. Infants show the expected pattern with FI schedules, more erratic patterns are seen in young children, and then there is a re-emergence of a temporally-regulated response pattern in 7-8-year-olds (Bentall & Lowe, 1987; Bentall et al., 1985). By the age of 7-8 years however children's behavior in experimental tasks is due to rules about the interval, not the direct contingency.

Research has also shown that duration estimates can be distorted depending on contextual variables (Droit-Volet & Gil, 2009). For instance, when attention is diverted away from the duration of an event, intervals may be judged shorter while longer estimations of intervals may be made when specifically attending to the passage of time (Block et al., 2010; Coull et al., 2004; Zakay & Block, 1996). Other research in adults and children has shown that different "emotional stimuli" (e.g., pictures of facial expressions depicting high/low arousal or positive/negative valence) can influence estimates of duration (Angrilli et al., 1997; Droit-Volet & Meck, 2007; Gable & Poole, 2012). Gil et al. (2007) showed that on a temporal bisection task with pictures of angry and neutral faces, 3-, 5- and 8-years-olds estimated the duration of angry faces to be longer than that of neutral faces. In another study with university students, Fayolle et al. (2015) found that when a stimulus was paired with a mild shock during a temporal bisection task, participants judged the durations to be longer than trials with no shock. More accurate duration estimates have also been observed when participants are made aware of attention- or emotion-related time distortion (Droit-Volet, Lamotte, et al., 2015; Lamotte et al., 2012).

RFT Extension

Some studies suggest that rules are relevant to children's timing responses (e.g., Droit-Volet, 1998; Pouthas et al., 1990). RFT sees relational framing as central to rule-following and thus also to timing tasks that involve experimenter delivered verbal instructions or self-verbalized strategies. Attending to the temporal features of the timing task has been highlighted as important to performance (Block et al., 2010; Lamotte et al., 2012). In typical timing tasks, providing verbal instructions plays a critical role in bringing a child's behavior under the control of the temporal features of the task. Droit-Volet (2013) stated that as children become able to understand instructions used in experimental timing tasks around the age of 3 years, the methods used shift towards those also used with adults. RFT might help provide further precision around specifically which relational framing skills are necessary to enable children to respond on such tasks as well as how performance on such tasks might be improved.

As one example, consider a novel instruction used within a verbal production task of timing abilities such as, "Say start and then stop when one minute has passed" (Block et al., 1999). To accurately follow this instruction, the child must derive a temporal relation under control of the contextual cue "then" within the instruction (i.e., saying "start" comes before saying "stop"). This temporal relation is important to the sequence or order in which the child's vocal behavior occurs in this example. However, this temporal relation (saying "start" then "stop") is also made more specific by speaking of the stimulus event as having an end and adding quantification (one minute) to the relational context. A child with a longer and more extensive history of reinforcement with respect to equivalence relations between duration words (e.g., 1 minute, 10 minutes, 1 hour, etc.) and the corresponding amounts of time passed would likely perform better on this task. As a child learns to verbally relate duration words with passages of time, a gradual improvement of explicit timing abilities would be expected as this may coincide with more precise rule-control.

Learning to arbitrarily relate words as equivalent to quantities (involved in learning to count) and applying this to the temporal dimension of stimulus events allows for more precise relations to be derived. This may be especially relevant to explicit or verbal timing. For instance, utilizing counting strategies to keep track of the passage of time becomes advantageous as our temporal estimates are not always reliable (Droit-Volet, 2011). Research shows an increasing shift as children age towards using counting or quantification strategies (Espinosa-Fernandez et al., 2004; Levin & Wilkening, 1989; Wilkening et al., 1987). RFT suggests that as a child's AARR repertoire improves, there is an increased opportunity to engage in verbal strategies to time events and to act more effectively in one's environment. Rules to withhold behavior ("Wait until X amount of time has passed,") or persist in behavior ("Keep going for X amount of time") may be more functionally useful when arbitrary quantitative relations are accurately applied to the rule.

Research could examine at what ages certain relational frames are typically acquired and how this impacts timing behavior. At present, RFT research on temporal relations has been limited to investigations of derived relational responding with "before/after" and "now/then" cues or their functional equivalents. Deriving relations in accordance with "before" and "after" cues allows an individual to order events or sequence their own behavior (O'Hora et al., 2004); however this only enables a person to respond appropriately to event order, not to event duration. Applying quantification to durations of events can provide further specification of derived relations, which may be advantageous to timing behavior. As yet however, no RFT work has examined temporal relations that have been further specified with the quantification of durations and what effect this has on timing behavior. One direction for research might be to investigate whether training in equivalence relations between quantities and durations in children alters observed performance on timing tasks.

Another potential focus of RFT research relevant to timing might be to examine contextual conditions that influence duration estimation and passage of time judgments. Duration estimations can differ depending on the context, such as with emotion-stimuli (e.g., Angrilli et al., 1997). RFT would suggest that the direct and relational learning histories of a person are relevant, as these would establish particular functions of such stimuli, emotional or otherwise. Research could investigate how the functional properties of stimuli influence how quickly or slowly time seems to pass and importantly, whether transforming the existing stimulus functions through derived relations changes duration estimations. Additionally, some recent work has begun exploring how duration estimations are affected during mindfulness activities (Droit-Volet, Fanget, et al., 2015; Kramer et al., 2013; Wittmann & Schmidt, 2014). Future RFT research could examine such phenomena in more functional behavioral terms. For example, through temporal frames and AARR more generally, verbally constructed past or future events could be imagined which might affect attendance to present moment contingencies. It has been stated that mindfulness activities aim to strengthen observing responses toward nonarbitrary features of the current environment while reducing the dominance of AARR about past or future events (Belisle & Dixon, 2021; Tarbox, Szabo, et al., 2020). It might be useful to use this functional conception to examine the effect of relevant experimental analogs of such processes on the subjective experience of time.

Acquisition of the Clock and Calendar Systems

Summary

Another key repertoire important to an understanding of time as an abstract verbal concept is using the clock and calendar systems. These conventional systems are used pervasively in societal organization and are advantageous tools to adaptive functioning and independence. An adult-like use of these systems requires an understanding of both temporal order and temporal duration. Other skills important for appreciation and use of these conventional systems include familiarity with repeating sequences and temporal perspective.

Mastery of the clock and of calendar systems are acquired gradually during childhood (McCormack & Hoerl, 2017; 2020; Thornton & Vukelich, 1988). Friedman and Laycock (1989) showed that children are able to tell time on digital clocks and to tell the whole hour on analog clocks by 6-7 years, to tell half-hour time on analog clocks by 7-8 years, and to tell the time to the minute by 9 years, albeit errors were still observed in some children up 10-11 years. The researchers also showed that the skill of transforming the time on a clock (e.g., correctly answering the question, “What time would it say in 30 min?”) tended to emerge by the upper-elementary school years. With other time units, children 6-8 years can order the days and seasons but have difficulty with the cyclical aspect of time, such as that fall-winter-spring-summer and spring-summer-fall-winter are both correct sequences (Friedman, 1977, 1982). Between 8-10 years, ordering months, sequencing from different starting points, and referencing the calendar when describing the nearness of past/future events improves (Friedman, 2000; Friedman et al., 1995).

Tartas (2001) tested 200 children between 4-10 years using an interview task involving “when” questions (e.g., “When do you go for break at school?” “When does Christmas happen?” etc.) and a card ordering task about daily, weekly, and annual events. Results showed that as children age, there was a gradual shift from answering with relative temporal locations (e.g., “First we go to the toilet and then we go for break”) to more absolute locations in their responses (e.g., “We go for break in the morning,” or “We go for a break at 10:00 am”). By 5-6 years children used days of the week to order events, between 6-8 years they began to use hours to do so, and by 8-10 years they began to use months of the year.

Recently, Tillman and Barner (2015) found that understanding of the relative order of duration words compared to each other (e.g., “day” > “hour” > “minute”) emerges and gradually improves between the ages of 4-6 years. However, an understanding the absolute durations of these words and their proportion to each other (e.g., how much longer an hour is than a minute) did not occur until later in childhood. The 6-7-year-olds who had learned the formal definitions of the duration words (e.g. that 1 hour = 60 minutes) performed better than those who did not on a task to represent their durations on a timeline. Tillman et al. (2017) observed a similar trajectory with the acquisition of deictic terms, such as “yesterday” and “tomorrow” using a timeline-based task. Between the ages of 4-6 years, children gradually improved in their understanding of deictic status (e.g., “last week” is in the past, “tomorrow” is in the future) and relative order (e.g., “tomorrow” comes before “next week”). It was not until after 7 years however, that an understanding of remoteness from the present (e.g., how much further “next week” is than “tomorrow”) emerged. These authors also indicated that these latter skills develop around the time clock reading is emphasized in school and that explicit instruction may facilitate these repertoires.

RFT Extension

Acquisition of conventional time concepts can take years to be fully mastered. The clock and calendar systems are socially-constructed arbitrary systems that require explicit instruction (Nelson, 1996b). As such, future research might investigate whether difficulties with time concepts in these conventional systems correlate with deficits in AARR and whether training derived relations when learning conventional time units offers benefit to educators and practitioners. Research could compare using an RFT approach focusing on systematically training temporal AARR at various levels of complexity with existing educational approaches to determine whether the former might lead to faster acquisition of key clock and calendar terms. Research might also investigate whether an RFT approach can be successfully used to train these relatively complex skills at younger ages than previously observed or when deficits are present.

Using these conventional systems successfully requires a number of relational skills, not only temporal frames. Duration words are related with their equivalent lengths of time, and these words are also related to each other as well as to other non-duration words in various ways including comparatively, hierarchically, and deictically (see for example Table 2.2). An RFT approach would suggest that relating time words and conventional units in a variety of ways is critically important to a verbal understanding of time. Children often receive repeated exposure to some of these terms in educational settings such as by reciting the days of the week or months of a year during a calendar time. Friedman (1990) noted that although children can verbally list names of days and months for example early in childhood, it is not until a later age that they begin to use these terms more flexibly. A young child may be said to “know” the days of the week, but this does little to evaluate in what contexts they are able to use these terms relationally. RFT provides a more systematic way to evaluate the understanding and use of these terms by emphasizing instruction on key relational patterns involved, use of MET to train these patterns, and testing of relevant derivation and transformation of function.

While conventional time units can be related in a variety of ways, certain mathematical skills are also clearly needed for mastery of the clock and calendar systems. On one level, acquiring basic equivalence relations between durations and arbitrary words is useful (e.g., 1 week is 7 days), but this is also likely insufficient on a broader level. This relation for example does little to help a person derive subsequent equivalencies for other durations such as how many days 2, 3, or 4 weeks is. It is a quantified comparison relation (i.e., a week is 7 times more than a day) that enables a person to derive answers to these examples. Without such numerical relational skills, direct training would still be necessary to solve novel problems involving durations.

Table 2.2

Example relational patterns with time units

Relational Pattern(s)	Examples
Coordination	An hour is the *same as* 60 minutes. 7 days is the *same as* 1 week. November is the *same as* "11."
Distinction	24 hours is *different than* 365 days, 12 months, and 1 year. Weekdays are *not* weekends. Leap years are *different than* other years.
Opposition	Morning is *opposite to* evening. Noon is *opposite to* midnight. 3:00 PM *is opposite to* 3:00 AM.
Comparison	A year is *more* time than a week. 30 seconds is *shorter than* 1 hour. An hour is *longer than* a second.
Temporal	April is *after* March. Spring is *before* summer. 11:30 AM is *earlier than* 2:00 PM.
Hierarchical	Years *contain* months, months *contain days*, days *contain* hours. Halloween is *in* October. Winter is a *type of* season.
Deictic	*Today* is Thursday, *tomorrow* is Friday. *This* month is June, *last* month was May. *Now* it is the afternoon, *later* it is the evening.
Relational Network	If right *now* it *is* Christmas, New Year's is *sooner than* Valentine's Day. *Tomorrow* morning is *before next* week. *Last* month *was* February, so *this* month is *longer*.

Y. Barnes-Holmes et al. (2001) suggested that a history of AARR is needed prior to solving number-series problems commonly used with identifying numerical patterns, which shares similarity to deriving mathematical relations between time concepts. Developmental research has shown that comprehension of relative order between duration words (e.g., a year is more than a week) develops earlier in children than absolute duration (e.g., how much longer a year is than a week) (Tillman & Barner, 2015). Similarly, understanding relative order of deictic time words (yesterday happened after last week) precedes remoteness from the present (e.g., how much further from the present last week or yesterday are) (Tillman et al., 2017). Although this work did not test for derived relations specifically, from an RFT view, the results are understandable as simpler instances of AARR would be needed prior to deriving relations that are made more precise with quantification.

Training derived relations might also be integrated with learning time estimation of events in younger children even before certain mathematical skills are established. One curricular activity used in educational settings is for students to match different activities of varying durations to their estimated length in time units such as, seconds, minutes, and hours. MET could be included with teaching how much time each of these words refer to. Multiple events that take around a few seconds, minutes, and hours relevant to the child's life might first be selected. The instructor would then explicitly train relations of coordination between the events and corresponding time units using standard reinforcement and error correction procedures. Once mastered, novel events that the child has not had previous training with or exposure to, might then be used for generalization and to test for derivation. The instructor could train a relation of coordination between a novel event (e.g., a bike ride to the store) and a previously trained event that takes a similar amount of time (e.g., eating dinner). The child could then be asked how much time it would take to get to the store and a derived relation would be demonstrated if the novel event is matched to the correct time unit. This could be extended beyond just matching as well, such as by using a timeline-based task representing a continuum of "less time" to "more time." Comparative relations between events could be trained and derived relations tested for. A transformation of function could then be assessed by having the child correctly sequence pictures of the events along the timeline.

Self-Control

Summary

Another key repertoire related to an understanding of and engagement with varying temporal durations is self-control. From a behavioral perspective, self-control has been understood as choice-making behavior in which a person chooses a larger delayed reinforcer over a smaller immediate reinforcer (Schweitzer & Sulzer-Azaroff, 1988). Self-controlled responding is an adaptive skill as delayed outcomes are likely to be encountered in the natural environment and may also support social behaviors like sharing and cooperation (Stromer et al., 2000). Impulsive behavior has been described as the inverse: choosing the smaller-sooner reinforcer over the larger-later reinforcer.

In the behavior analytic literature, the presence of additional antecedent stimuli that signal delays to reinforcement has been suggested as a factor that may influence self-control responses. A few studies have found that adding signals, such as hand gestures, timers, or verbal instructions to wait may assist with reducing impulsive responding (Grey et al., 2009; Vollmer et al., 1999). Newquist et al. (2012) however, found conflicting results as rules and timers were insufficient for increasing self-control responses in three pre-school aged children. Whiting and Dixon (2015) highlighted a variety of behavior analytic approaches that have successfully been used to improve self-control responses, such as progressive schedules of reinforcement (Schweitzer & Sulzer-Azaroff, 1988), presenting concurrent activities during the delay (Binder et al., 2000), introducing choice and an illusion of control (Dixon & Tibbetts, 2009), and integrating group contingencies (Dixon & Holcomb, 2000).

Developmental research has explored self-control responding in children with methods such as delay of gratification tasks (Mischel et al., 1989). In these tasks, a child is typically given the choice between receiving a smaller preferred item immediately (e.g., one sticker) or waiting for a period of time and receiving more of the preferred item (e.g., multiple stickers). Research with children has shown that the likelihood of choosing the delayed reward in this context correlates with age (Mahy et al., 2020; Miller et al., 1978; Mischel & Mischel, 1983; Mischel et al., 1989; Moore et al., 1998; Prencipe & Zelazo, 2005). Different explanations for these age-related differences have been suggested such as the development of inhibitory control and improvements in Theory of Mind skills that facilitate consideration of one's future desires relative to present desires (Mahy et al., 2020).

Researchers have also explored this topic in connection with the phenomenon of delay discounting, which refers to the tendency for individuals to devalue delayed rewards (Madden & Bickel, 2010). There is evidence that discounting rates are decreased on delay discounting tasks when participants are given a cue paired with the larger-delayed reward to imagine upcoming positive future events (Daniel et al., 2015; Daniel et al., 2013; Peters & Buchel, 2010). By verbally contacting the future events in a vivid manner (i.e., episodic future thinking), it is believed that the value of the delayed reward is altered and thereby influences choice-making (Benoit et al., 2011). For instance, Peters and Buchel (2010) had participants construct a list of upcoming planned events in their lives and then used these events as tags that appeared during a delay discounting task. That is, on trials to select smaller-immediate or larger-delayed rewards, statements such as "vacation Paris" or "birthday John" appeared on the screen indicating the event they had planned for that day. Data showed decreases in delay discounting rates in the experimental group that received these statements during the task. Other research has shown that the type of imagined future events has differential results on delay discounting rates. Liu et al. (2013) showed that imagining future preferred events (e.g., a party) showed decreased discounting rates, while aversive events (e.g., getting sick) increased discounting rates, and presumed neutral events (e.g., washing clothes) produced no difference compared to a control group.

Another strategy that has been shown to decrease discounting is having persons connect to and choose for their "future-self." Bartels and Urminsky (2011, p. 193) argued that when a person perceives their future-self as, "more closely connected to the current-self in terms of sharing important psychological properties, such as beliefs, values, and goals, the decision maker is more motivated to act patiently, furthering the later-self's welfare." Across multiple experiments, the authors demonstrated that instructing participants on continuity in identity between the self-now and the self-later influences discounting. Other future-self studies that have seen reductions in discounting have used different methods, such as showing participants a virtual avatar depicting a future representation of themselves before completing a discounting task (Hershfield et al., 2011; Kuo et al., 2016). In their systematic review of behavioral trainings and manipulations to decrease delay discounting, Scholten and colleagues (2019) found that these types of future-oriented manipulations were among the most promising research directions.

RFT Extension

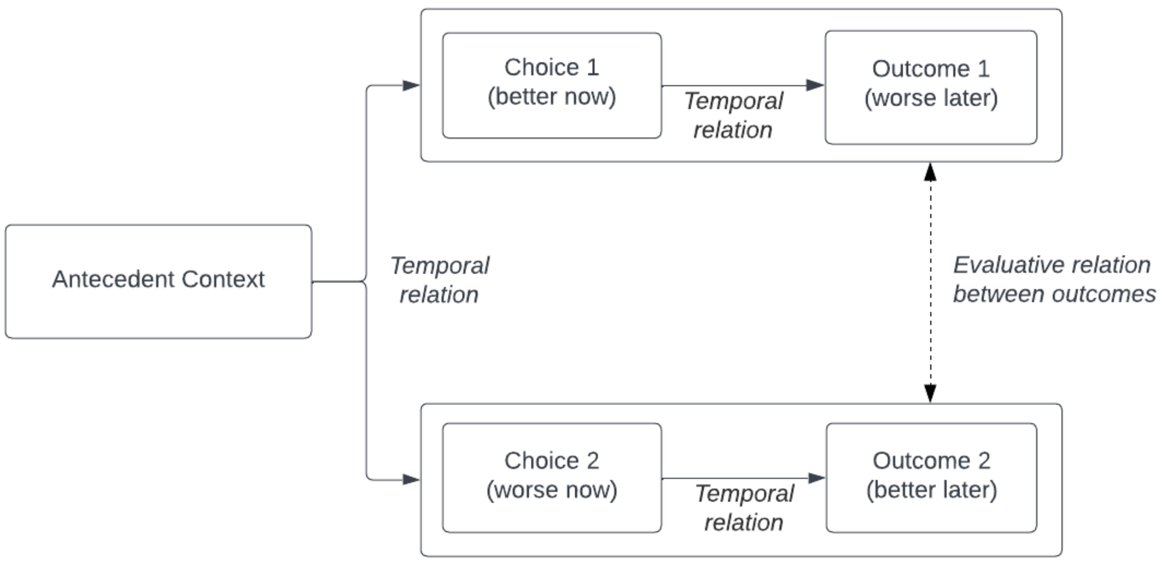
Examining the role of temporal and other relational frames more directly may provide further insight into how self-control responding develops in childhood as well as language-based procedures for training such responses. Existing behavioral approaches to self-control, such as working with direct contingencies, may require extensive training. Further investigating verbal interventions to teach self-control may be worthwhile if it requires less time to reach similar outcomes or can augment other procedures (Whiting & Dixon, 2015).

Twohig et al. (2007) suggested that with a developed AARR repertoire, "self-control rules" such as, "if (behavior) then (better consequence) after (delay)," can be used by self or others. Following this type of rule necessitates at least three relations: temporal (a sequence of behavior, then X amount of time, then consequence), coordination (between words and events), and comparison (evaluating the immediate and delayed consequences). A person may understand a rule like this, though to follow the rule a transformation of function is also needed to provide the behavior-controlling properties to the rule (Harte et al., 2020). In this case, transformation of function via temporal and coordinate relations allows for the verbally constructed events to have stimulus functions (i.e., the likelihood of demonstrating a behavior in the moment may be influenced by temporally framing a preferred future event as coming after the behavior). The transformation of functions through comparison relations decreases the impact of the smaller-immediate consequences and increases the impact of the larger-delayed consequences. Accordingly, a sufficient reinforcement history for rule-following in accordance with these verbal relations is necessary for this type of rule to be effective (D. Barnes-Holmes et al., 2001). Little empirical work on establishing this type of rule-governed behavior in children has been done, though some work has shown that autistic children can be trained in preliminary rule-following repertoires with antecedent-behavior (Tarbox et al., 2011) and behavior-consequence relations (Wymer et al., 2016).

Theoretically, once acquired, the capacity to respond in accordance with such self-control rules may then be useful at different points of time in influencing choices between smaller-sooner or larger-later consequences. Events can be put in relational networks that describe temporal sequences or behavioral contingencies *before* a person has the opportunity to respond. If a person with a sufficient relational repertoire is told ahead of time (or self-derives) that a larger amount of a preferred item comes after waiting, while a smaller amount comes after not waiting, these rules may transform the function of each choice and thereby alter the likelihood of engaging in the self-controlled response. Comparing these networks in a visual format (e.g., behavior mapping) may help make the relations more salient, particularly for younger children (Figure 2.4). Secondly, some research on self-control training has also shown that rule statements can be used in the form of mediational responses *during* delays to enhance self-control (Binder et al., 2000; Toner & Smith, 1977). For instance, children can be taught to quietly or covertly repeat a verbal response such as, "When I wait quietly, I get what I want" (Hanley et al., 2007, p. 284) to promote delay tolerance. Other concurrent activities can be used to a similar effect (Binder et al., 2000), though verbal behavior of this type may be advantageous for a child with a sufficient relational repertoire. Such behavior can be used in any type of situation, does not rely on the availability of additional materials, and opportunely directs focus towards the larger-delayed consequence. AARR might also be beneficial *after* the consequence for a choice has been experienced. Even if the immediate choice was still selected, an individual with an AARR repertoire can describe their choice of selecting the smaller option and relationally compare it to the larger-delayed option. In turn, the selected item may be transformed to have less reinforcing properties as a result of this comparative framing (D. Barnes-Holmes et al., 2001; Stewart et al., 2012). Engaging in AARR after the consequence is experienced and the resultant transformation of function may then serve as an additional source of influence to alter subsequent future responding. More simply, a person "reflects" on their choices after the fact and considers behaving differently in similar future contexts.

Figure 2.4

Example Visual Display of Comparing Relational Networks



Using an RFT-based approach to self-control training has been recommended as a future approach as it provides a technical way to account for the influence of verbal behavior on choice making (McKeel & Dixon, 2014). RFT suggests that as an individual increasingly acquires AARR, it becomes possible to transform the function of the immediate and delayed consequences through language. Dixon and Holton (2009) showed that transforming the function of stimuli may affect how individuals respond to immediate and delayed reinforcers. In their experiment, five participants with a gambling disorder first completed a delay discounting task on a computer in which two irrelevant colored stimuli were presented alongside the smaller-immediate and larger-delayed options. Participants then completed a relational responding task in which the same two arbitrary colors were trained as contextual cues for “better than” and “worse than” relations with sets of quantitative gambling stimuli. Once relational training and testing was complete, participants again completed the delay discounting task that incorporated the arbitrary stimuli. Due to the relational history, the stimulus functions of the colored stimuli were now transformed in accordance with “better than” and “worse than” relations. Results showed that participants subsequently made more larger-delayed responses compared to baseline. This study provided initial evidence that impulsive responding may be altered by the transformation of stimulus functions in the absence of reinforcement for choosing self-control responses.

This RFT-based approach could be extended to other frames. It has been suggested that temporal relational frames are of special importance to delayed responding as, “learning to describe environmental sequences and delays may considerably reduce the interference of alternative events in accounting for delayed consequences” (Hayes, Gifford, et al., 2001, p. 99). For example, it might be investigated whether training children both directly on nonarbitrary duration estimations, as well as on derivation through temporal AARR of previously untrained durations, might alter delay-discounting behavior.

Research might also look at the methods used with the future-oriented manipulations from an RFT approach. In episodic future thinking manipulations (e.g., Peters & Buchel, 2010), temporal frames in particular may play a key role in enabling a person to verbally-construct hypothetical future events. From an RFT view, imagining future scenarios in “vivid” detail might be explained in terms of contextual control by the displayed phrases/instructions producing temporal AARR that allows momentary transformation of perceptual stimulus functions. As a result, the relative reinforcing value of the immediate and delayed options during the task are altered. In future-self manipulations, the “self” is being related in different ways that can alter discounting rates. Bartels and Urminsky (2011) for example, showed that the participants that read a short passage about how the person they are and the traits they have remain stable over time were more likely to select larger-delayed options with actual gift cards than participants that read a passage on how the person they are and the traits they have change over time. From an RFT view, this could involve relating relational networks in specific ways. Presenting relations of coordination between the deictic (interpersonal-temporal) relations of self-now and self-later may support self-control responding in contrast to presenting a relation of distinction. There has as yet been no RFT work that has modeled such processes in terms of transformation of function through temporal relations. Such research might support additional understanding of the key processes involved and lead to new practically oriented insight into how such exercises can improve choice making.

Planning and Time Management

Summary

Planning as a skill includes identifying a terminal goal and the steps or resources needed to reach the goal, initiating and monitoring progress, and completing the plan (Najdowski, 2017). In a review by McCormack and Atance (2011) on the development of planning in children, the authors suggested that planning involves three forms of flexible thinking. The first is representing time in an event-independent-manner. This refers to representing different points in a temporal sequence in a flexible way that allows for their reordering, including selecting which actions should occur at any point in the sequence. For example, doing action A before action B may lead to outcome C, which may be a different outcome than if action A is done after action B. Effective planning then, may involve thinking of not only which actions are needed to achieve a goal, but also in which order those actions should occur (McCormack & Hoerl, 2017). Secondly, executive function components, such as inhibitory control, are suggested as important, though they say that more research is warranted. Third, self-projection (or temporal perspective taking), refers to the ability to shift to alternative past or future perspectives that are not the here-and-now (Buckner & Carroll, 2007). McCormack and Atance suggest that these three skills can be used as a framework to examine the research on the development of children's performance on planning tasks.

A few different methods have been used to study planning in children. Tower tasks, such as the Tower of London (Shallice, 1982), involve moving objects around within a certain problem space from their initial position to a goal position in the least number of moves possible while adhering to certain rules. Planning skills are considered relevant to tower tasks since thinking of possible sequences of moves and their outcomes (without manipulating the objects) would presumably lead to better performance. Luciana and Nelson (1998) tested children between 4-8 years on problems at various difficulty levels (i.e., the minimum number of moves needed to complete the task) and found an increased ability and efficiency in solving these problems with age. Some research has indicated that these tasks are particularly difficult though for children under 5 years (Bull et al., 2004; Kaller et al., 2008).

Another approach is the route-planning task, in which children are given a model location (e.g., a store) and toy character, and need to plan the most efficient route through the location while completing the objectives (e.g., shopping for selected items). Gauvain and Rogoff (1989) compared performance between 5- and 9-year-olds on this task and found older children planned more in advance and produced more efficient routes. Simplified variations of this method have also been designed for use with younger children (Carlson et al., 2004; McColgan & McCormack, 2008). For instance, McColgan and McCormack (2008) tested 3-5-year-olds on a single trial planning task in which a doll visits a model zoo and wants to take a picture of a kangaroo. The children were tasked with identifying a location in which a camera can be stored so that the doll can pick it up along the path. Only the 5-year-olds reliably passed the task by selecting a location on the path that the doll would encounter before rather than after reaching the kangaroo.

The aforementioned approaches examine planning in the context of solving an in-the-moment problem. Other studies have however investigated children's planning for more distant or hypothetical future situations. In one study, Atance and Meltzoff (2005) presented 3-5-year-olds with stories and pictures of future events that would evoke a certain physiological state. The researchers asked the children to select an item they would need to take with them and to vocally explain the choice. For example, when a scene depicting a waterfall was shown, a correct response was to select the raincoat from an array with distracters and to provide an explanation such as, "I might get wet." Across all ages, children tended to select the correct item while 4- and 5-year-olds provided a significantly greater proportion of explanations about a future state than the 3-year-olds. In a follow up experiment, the researchers replaced one of the distracters with an item that was semantically associated with the picture scene (e.g., a picture of rocks for the waterfall scene). Performance in 3- and 4-year-olds was significantly affected as there was an increased tendency to select the semantically associated item.

A related skill set, time management, involves: a) scheduling activities based on duration estimations of each activity, b) checking the time during the activity to determine if one is on or off track with the schedule, and c) continuing or adjusting one's behavior or the schedule to be on time for subsequent scheduled obligations (Najdowski, 2017). Said another way, a person engages in self-management of their own behavior within a given time frame (Barkley, 2013; Claessens et al., 2007). Conceptually, time management could be approached as a broader repertoire that involves the previously described skills of sequencing, duration estimation, use of conventional time systems, self-control, and planning. A few prerequisite skills to time management that have been noted include telling time, making and following a schedule, and estimating the duration of activities (Dawson & Guare, 2010). Between 8-11 years children perform tasks such as planning simple school projects, keeping track of changing daily schedules, and may plan for how to earn money. By 11-14 years, children are tasked with following complex and changing school schedules, planning and completing long-term projects, estimating time needed to complete tasks, and adjusting their schedule (Dawson & Guare, 2009).

Presently, behavior analytic research investigating the training of these repertoires is scarce. Multiple curricular or educational resources have been developed however, that aim to improve planning and/or time management, among other skills (Cannon et al., 2021; Dawson & Guare, 2010; DiPipi-Hoy & Steere, 2016; Najdowski, 2017). For instance, Najdowski (2017) suggests that practitioners can utilize standard behavior analytic principles such as reinforcement, prompt fading, chaining, and MET to train these repertoires. The teaching approach suggested for planning involves training learners to first identify a short-term goal (e.g., clean the bedroom) or long-term goal (e.g., school project), identify the needed materials, task analyze the relevant steps, and then initiate, monitor, and complete the plan. For time management, learners are taught to identify and predict how much time activities take, and then make and follow a schedule. For each of these repertoires, different activities and routines are used as exemplars to promote generalized responding as opposed to only learning a specific task.

RFT Extension

Mainstream psychological approaches to skills associated with planning and time management are often examined in context of executive function (Barkley, 2011, 2012). Executive function refers to "self-directed actions needed to choose goals and to create, enact, and sustain actions toward those goals" (Barkley, 2012, p. 60). Some authors have conceptualized that executive function could instead be approached as a subset of rule-governed behavior by examining the conditions in which people, "select among available rules or generate new ones, follow rules when they are available even though they conflict with other sources of behavioral control, and change them when they no longer work" (Hayes et al., 1996, pp. 292-293). One RFT-based observational study has explored patterns of relational framing that may occur during a common task of executive function (Wisconsin Card Sorting Test; WCST). Tyrberg et al. (2021) presented the WCST to adult participants and asked them questions during the task about their responses (e.g., "What do you think you can do now?" "Why do you think that was correct/incorrect?"). The authors recorded responses and analyzed transcripts by identifying relational patterns based on the types of contextual cues emitted by participants. The authors reported that participants appeared to engage in deictic and temporal framing during critical points of executive function activity (category shifts during the task). Continued research in this domain may lead to further clarity on conceptualizing executive function related abilities in behavioral terms and whether targeting temporal and/or deictic framing for intervention leads to changes in performance on measures like the WCST.

Regarding the literature on planning in children, two areas are suggested for future investigation. One, McCormack and Atance (2011) note that research is lacking on the relation between children's understanding of "before/after" and their planning abilities. For instance, route-planning tasks (McColgan & McCormack, 2008) involve manipulating events in before-after sequences, so an accurate use of these terms may be of benefit to successfully pass these tasks. RFT research might address this limitation by training these words as contextual cues for temporal framing and evaluating whether this influences performance on such planning tasks. Similarly, performance on temporal framing tasks could be compared to scores on future-thinking measures, such as the Children's Future Thinking Questionnaire (CFTQ) which measures the future-oriented skills of planning, prospective memory, episodic future thinking, saving behavior, and delay of gratification (Mazachowsky & Mahy, 2020). Secondly, some experimental tasks in the cognitive developmental literature investigate planning to obtain a goal in the present environment (Carlson et al., 2004), while others investigate planning for a hypothetical future goal (Atance & Meltzoff, 2005). RFT research might look to investigate the types of relational repertoires needed for each of these contexts and more specifically to what extent temporal framing plays a role.

Conceptually, temporal or causal relations are important in rules and this is particularly true for rules around planning and time management. An advantage of planning actions ahead of their occurrence is that it allows for individuals to verbally contact contingencies that are not in the immediate environment or have not previously been directly experienced. By verbally constructing multiple contingencies, a person can then select the action(s) for the present moment that will best achieve the intended outcome(s). Relationally, this type of verbal problem-solving is made possible through temporal and comparison (evaluative) frames (Hayes, Gifford, et al., 2001; Hayes et al., 2007). Temporal framing puts behaviors and consequences into particular sequences, and these sequences can then be related to alternative sequences through comparison framing. By relationally responding in this manner, a person can then select the most useful response(s) relevant to the context. Engaging in further relational responding, (e.g., a "pros and cons" activity), could abstract additional features of the context that may help with effective planning and decision making (Hayes et al., 1996).

Adaptive rules can be used to plan and manage time in other ways. For instance, one aspect to managing time includes prioritizing activities and deciding at which points in time each should be completed (DiPipi-Hoy & Steere, 2016). By prioritizing, a temporal order of activities can be constructed. For example, one well-known strategy is to sort activities based on their urgency and importance (i.e., the Eisenhower matrix). Tasks that are sorted as both "urgent" and "important," are selected to be completed sooner than the activities that are sorted elsewhere. AARR is key to successfully using a rule-based strategy such as this. Activities are related in frames of coordination or distinction with the verbal relata "urgent" and "important." Sorting based on "urgency" also involves framing how soon tasks need to be completed relative to now or another point in time (deictic, temporal) and therefore which events are more or less urgent (comparison). The relative "importance" of a given activity is context-dependent and involves relating events comparatively to other events.

A potential challenge in managing one's time is that preferred activities may interfere with activities that are neutral or aversive. Temporal framing may be useful in this instance, as it allows the person to verbally contact the differential consequences of completing each task. The person can think through what possible outcomes could happen in the future if each activity is completed (or not completed) sooner or later. This may help to transform how "important" a given activity is since neutral or nonpreferred tasks are then framed as coming before a delayed, but more preferred consequence (e.g., "If I can finish [aversive activity] today, then later this week I will have more time for [preferred activity]). Hierarchical framing with values-based strategies may also help to form adaptive rules for managing various activities in a time frame. In the RFT literature, a value has been defined as the highest point in a hierarchical relational network of life activities (Barnes-Holmes, Barnes-Holmes, McHugh, et al., 2004). Acting in accordance with one's values then involves the transformation of consequential functions through this hierarchical relation (Plumb et al., 2009). Performing certain less-preferred tasks can be hierarchically related as belonging to a particular value (e.g., “be persistent” or “responsible”). Framing in this way may lead to transforming the function of the lesser preferred tasks to become “more important” to the person as they become instances of a verbally constructed reinforcer.

However, time management requires more than simply creating or responding to a sequence of tasks in a particular temporal order (i.e., making and following a schedule). Relational responses such as relating durations as shorter or longer than others, following rules that include quantification, and deriving whether one’s progress over specified durations is sufficient to stay on schedule are likely key to effectively managing one’s behavior relative to time. RFT research could examine to what extent AARR repertoires, including especially various levels of temporal framing, are helpful for training planning and time management and in what ages these skills might best be taught.

In applied contexts, one way that a focus on AARR can be integrated within existing behavioral training approaches for planning and time management is with a “leading questions” prompting method (Najdowski, 2017). Najdowski suggests that instead of simply providing the learner a prompt for the answer during a task, leading questions are models for the kind of verbal behavior in which learners might engage while carrying out the steps of a task. Leading questions for planning might include questions like, “What are all the steps your plan includes?” “In what order will you do them?” or “What might happen if you did step X before step Y?” For time management, leading questions could involve asking, “How much time is that activity?” “How long did a similar activity take last time?” or “Which activity takes a longer amount of time to do?” (Table 2.3). From an RFT perspective, these leading questions help to teach a learner to engage in certain patterns of AARR before, during, or after they complete different steps of a task. In these examples, hierarchical relations help to identify possible behaviors involved in a complex task. Temporal relations bring a specific sequence to those behaviors and help to identify alternative consequences based on the order. Coordination relations help the learner to accurately estimate needed time, and comparison relations help the learner to prioritize order when thinking about which activities take more or less time. These prompts can then be faded to facilitate the learner’s engagement in similar relational responses in the presence of the natural discriminative stimuli alone. Future research could investigate whether training learners to engage in particular relational framing patterns at different points during complex tasks supports acquisition of generalized planning and time management repertoires.

Table 2.3

Example Planning and Time Management Relational Responses

Skill Area	Example Verbal Prompts	Relation
Planning	"What are all the steps your plan includes?	Hierarchical
	"In what order will you do these steps?"	Temporal
	"What might happen if you do step X before step Y?"	Temporal
Time Management	"How much time is that activity?"	Coordination
	"Which activity takes a longer amount of time to do?"	Comparison
	"How long did a similar activity take last time?"	Coordination/deictic

Conclusion

In summary, behavioral research has historically investigated human responses to time through respondent conditioning and operant conditioning paradigms, such as with performance on reinforcement schedules. Although this work provides some insight, behavioral approaches to human responding to time as an abstract verbal concept has largely been absent in the literature. In this chapter, RFT was introduced an approach that could be used to extend work in this area. Relational framing, and particularly temporal relational framing, was suggested as key to abstract or verbal time. A conceptual overview of temporal framing was provided and the present state of RFT research into this skill was discussed. Research shows that temporal relations are relevant to sequenced responding in the context of rule-based control, though empirical work is currently limited to typically developing adults with established relational repertoires. A range of important time-related repertoires that have been explored from various psychological approaches was then reviewed. Particularly, the discussion focused on the areas of temporal sequencing, timing, acquisition of the clock and calendar systems, self-control, planning and time management. The discussion also explored how an RFT approach focused in particular on temporal relational responding might amplify and extend the existing research in each of these areas, with a particular emphasis on potential improvements in training and supporting such repertoires in children.

With the advancements of RFT research on language, rules, and derived stimulus relations, it is possible to extend a functional behavioral approach into the key domain of a human understanding of time. RFT sees derived relational responding, and notably temporal framing, as critical in this respect. Investigating how this repertoire develops as well as how it may best be trained and supported may offer new insight as well as many practical applied advances.

Chapter 3.

Assessing Temporal Relational Responding in Children

Portions of this chapter have been accepted for publication:

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Acquiring an understanding of how events are temporally related to each other, both with respect to actual experienced events as well as with respect to events in a more abstract sense (e.g., as represented in a calendar) is critically important in young children's development, allowing them to communicate more precisely about events in their world and to advantageously organize their behavior in time. Examining how temporal understanding is acquired in childhood may ultimately help inform practical intervention to teach such skills when they are deficient. As discussed in Chapter 2, an RFT approach could be used to investigate several temporal skill sets. The focus of the present chapter is to explore one of these areas and provide a starting point for additional research. Arguably, a fitting starting point is to investigate performance on temporal NARR and AARR tasks across a variety of ages with contextual cues such as "before" and "after."

Research into children's temporal understanding has heretofore mainly stemmed from cognitive developmental and psycholinguistic perspectives. Clark (1971) examined comprehension of "before" and "after" in 3- to 5-year-old children by requiring participants to perform sequences of actions with toys when instructions using these terms were given. Findings indicated that comprehension of both terms improved with age and that based on error patterns, children appeared to acquire an understanding of "before" earlier than "after." Clark (1971) reported that when unsure of the meaning of the temporal term, the children appeared to use an order-of-mention strategy—responding as if the order of events matched the order of mention in the sentence. Using an order-of-mention strategy would suggest that less errors would likely occur with sentences in which the actual order of events and the order in which they are mentioned match (e.g., "The girl kicked the ball before she patted the dog," or "After the girl kicked the ball, she patted the dog") compared to sentences in which the event order and the order of mention do not match ("Before the girl patted the dog, she kicked the ball," or "The girl patted the dog after she kicked the ball").

More recent research has extended findings on "before" and "after" comprehension in children. McCormack and Hanley (2011) showed 3- to 5-year-olds pairs of video clips of two non-causal actions in a particular order (e.g., brushing teeth, then washing face) and the experimenter said a sentence using either "before" or "after" describing the sequence. Participants were then asked to point to the video pair on the screen that either matched or not with the sentence they had been given. Children performed better with matching-sentences and only 5-year-olds performed above chance levels with non-matching sentences. Blything et al. (2015) sought to determine the age at which children begin to shift towards relying on "before" or "after" terms themselves as cues for temporal order instead of relying on background knowledge of events or an order of mention strategy. They showed young children sequences of an animated character performing two actions while the experimenters manipulated the sentence structure that narrated the order of the actions. Children were then asked to select the picture of the activity that came first. Results suggested that 3- to 4-year-olds performed better on "before" sentences compared to "after," while sentence variation and performance on a test for working memory (digit-span task) predicted performance in 4- and 6-years-olds. The authors noted the difficulty of discriminating effects of memory from those of language development.

The production of temporal terms has been shown to appear as young as 2 years, while the comprehension and accurate use of these terms gradually improves over childhood (Busby Grant & Suddendorf, 2011; French & Nelson, 1985). Errors in comprehension of these terms in particular contexts have been demonstrated up to early adolescence. For instance, Pyykkönen and Järvikivi (2012) tested understanding of multiple events in children between the ages of 8 and 12 years. Children were given a questionnaire on order of events that included a variety of sentences depicting simultaneous or sequential events while the temporal terms' sentence placement varied across trials. Results demonstrated that the children's accuracy on comprehension questions about the order of events was affected by the position of the temporal terms "before" and "after" within the sentences. While performance generally increased with age, even the 12-year-old children did not perform to levels of accuracy shown by an adult comparison group.

Some developmental theorists have pointed to the acquisition of language as critical in a child's acquisition of temporal understanding. For example, Nelson (1996a, 2007a, 2007b) has argued that it is through verbal interactions, such as by sharing past and future experiences or through direct instruction of conventional time systems, that children learn how to temporally organize events and reference themselves in time. Moore et al. (2014) evaluated Nelson's interpretation of the relation between time concepts and language and intellectual skills in an aspect of their study with children between 5 and 10 years of age. Participants were tested on time concepts and their performance compared with that on standardized measures of verbal and intellectual abilities (PPVT-4, TONI-3). A variety of tasks was used to evaluate temporal event ordering abilities such as placing cards depicting events on a spatial layout indicating how near or far they were from the present, labeling time concepts, sequencing picture cards of events in forward and backward order, and answering questions about the relative order of related events. Results showed that performance on the temporal cognition tasks were significantly predicted by verbal abilities, thus providing empirical support for a relationship between language ability and temporal understanding.

Critically, a limitation of the current literature is that minimal research has been done investigating the environmental variables that influence the acquisition of temporal understanding. While some research has shown that feedback and other instructional arrangements can improve understanding of temporal order in sentences (Amidon & Carey, 1972; Ehri & Galanis, 1980), studies are largely descriptive in nature. Turning towards a behavioral approach may assist with addressing this limitation on training these skills due to an emphasis on both prediction and influence of behavior (Biglan & Hayes, 1996). One particularly relevant approach in this regard is Relational Frame Theory (RFT; Hayes, Barnes-Holmes, et al., 2001; Stewart, 2016), a contextual behavior analytic account of human language and cognition. Substantial empirical research now attests to the efficacy of RFT as a basis for teaching basic and complex language skills to children and adults with and without disabilities (Gilroy et al., 2015; Kirsten et al., 2022a; Ming et al., 2018; Newsome et al., 2014; M. O'Connor et al., 2017; Tarbox et al., 2011; Wymer et al., 2016).

RFT suggests that arbitrarily applicable relational responding (AARR) is a key generalized operant underpinning human language and cognition. Relational responding refers to responding to one stimulus in terms of its relation to another stimulus. Nonarbitrary relational responding (NARR) is based on the formal properties of the stimuli (such as selecting a stimulus because it looks larger than another stimulus) and has been seen in many nonhuman species as well as in humans (Giurfa et al., 2001; Harmon et al., 1982; Ming et al., 2018). AARR, in contrast, is based not on the formal properties of the stimuli being related but instead on contextual cues that specify the relation irrespective of formal properties; for example, if I am told that coin A is worth 'more than' coin B then I will treat coin A as larger in value and preferable to coin B even though they are similar in size. AARR has thus far been shown unequivocally only by humans (Dugdale & Lowe, 2000; Hayes, 1989; Lipkens et al., 1993). RFT suggests that humans show a variety of different patterns of AARR (frames) including coordination (sameness), distinction (difference), opposition, comparison (more/less), spatial relations (e.g., above/below), temporality (e.g., before/after), hierarchy (e.g., member of/class of), and deixis (Hayes, Fox, et al., 2001). Framing allows the child to derive novel untaught relations between events (e.g., if told that A is more than B and B is more than C, I could derive that A is more than C and C is less than A) and hence is key to acquiring generative language (Stewart, McElwee, et al., 2013). Critically from both a theoretical as well as a practical standpoint, RFT studies have provided substantial evidence that AARR is closely linked with language and cognitive abilities (Barnes et al., 1990; Barnes-Holmes et al., 2005; Cassidy et al., 2016; Cassidy et al., 2011; Colbert et al., 2018; Devany et al., 1986; Dickins et al., 2001; Hayes & Stewart, 2016) and that it is possible to establish a variety of different patterns of AARR or frames (Barron et al., 2019; Belisle, Stanley, et al., 2020; Berens & Hayes, 2007; Dunne et al., 2014; Kirsten et al., 2022b; Mulhern et al., 2018; Rehfeldt & Root, 2005).

While there is a variety of types of relational framing, all frames share three core properties. Mutual entailment refers to a bidirectional relation between two stimuli, such that if a participant is taught that A is before B, then they derive that B is after A. Combinatorial entailment refers to the combining of relations, allowing for new derivations. For example, if a participant is taught that A is before B and that B is before C, then they may derive that A is before C and that C is after A. The third property of relational framing is the transformation of function, in which the psychological function of a stimulus participating in a derived relation is changed or transformed based on the other stimuli to which it is related as well as the nature of the relation. For instance, if stimulus event B has an appetitive function and is derived as being after event A, then the functions of A may be transformed such that anticipatory responding occurs during this event.

From an RFT perspective, children acquire particular patterns of AARR through multiple exemplar training (MET), which involves exposure to a variety of exemplars in which the stimuli and/or situations differ but in which the specific relational cues for that pattern remain the same. Through a history of such reinforcement from their socioverbal community, children abstract the relevant relational cues that indicate how stimuli are to be related (Hughes & Barnes-Holmes, 2016) and thus acquire generalized patterns of AARR.

In addition, while NARR and AARR can be described as distinct classes of behavior, acquisition of AARR is typically preceded by and supported by the acquisition of NARR (see Stewart & McElwee, 2009). In other words, the child might first learn to relationally respond in the presence of particular contextual cues based primarily on nonarbitrary properties of the stimuli involved but with sufficient exemplars, their relational response can come to be applied to arbitrary stimuli irrespective of the physical properties involved. Indeed, there is now empirical evidence in the case of a number of frames showing that assessing and/or training NARR can promote acquisition of AARR (Berens & Hayes, 2007; Zygmont et al., 1992).

With respect to temporal AARR, as in the case of other relational frames, RFT suggests that this repertoire is established through MET and also that children learn temporal NARR before learning AARR. More specifically, RFT suggests that children likely first learn to relationally respond with respect to events actually experienced in time (NARR) and subsequently learn to derive temporal relations between events without having to actually experience them; for example, if given two hypothetical events A and B, and told that A is after B, they could derive that B is before A (AARR; Hughes & Barnes-Holmes, 2016).

With regard to RFT research on temporal relational framing, O'Hora and colleagues (2004) provided the first relevant study, which was focused on relational responding in the context of instructional control. They trained and tested 12 university students on a computer-based relational responding protocol that involved "before/after" and "same/different" relations. Two arbitrary symbols were trained as contextual cues for "before" and "after" by reinforcing participants' selection of a statement that included one of the arbitrary symbols that accurately described an observed sequence of shapes. Participants were subsequently tested for instructional control on a task that involved pressing computer keys in a particular order specified by the arbitrary relational networks involving the "before/after" and "same/different" cues. Eight of the twelve participants showed responding in accordance with the arbitrary relational networks and participants who demonstrated instructional control in a second experiment additionally showed generalized responding to novel stimulus sets. A set of follow up studies (O'Hora et al., 2005, 2008) extended this work by showing that performance on the relational responding protocol correlated with performance on standardized measures of intellectual ability in university students. Other research relevant to temporal relational responding has focused on comparing accuracy and response latencies to arbitrary "before" and "after" cues on tasks of nonarbitrary sequenced responding. Overall, studies have shown that adults respond slower on “after” trials than on “before” trials (Hyland et al., 2012; 2014) and with less accuracy (Brassil et al., 2019; McGreal et al., 2016).

Existing RFT studies on temporal relational responding have been limited to investigation with typically developing adults with already developed relational framing repertoires. Research on the acquisition of temporal relations in young children without such advanced repertoires on the other hand is almost non-existent. Thus far, just one study has looked at temporal framing in children. Kirsten and Stewart (2022) examined a number of different varieties of relational framing in a cross section of young children between 3-7 years and in doing so provided some evidence that temporal framing may emerge later in development than other types of framing. However, one of the limitations of this study was that, because it involved surveying performance of young children on a number of different frames, the scope of testing in the case of particular types of framing was very limited. As such, these data on temporal framing in young children are perhaps not quite as informative as they might otherwise be.

Despite the limitations of past research on temporal framing, however, this work has provided at least a starting point for further exploration, such as by evaluating temporal relations in different populations. The aim of the present study is to investigate performance on tasks of temporal relational responding in young, typically developing children between the ages of 3 and 8 years. The present study utilized an RFT-based protocol to assess temporal relational responding at increasing levels of complexity. This involved testing children on tasks of nonarbitrary temporal relations and arbitrary temporal relations, including assessing for properties of mutual and combinatorial entailment, and transformation of function. We intended that this exploratory study would be an initial step that might help facilitate future research to examine the acquisition of temporal relational responding in more detail and to design appropriately targeted training procedures if this repertoire was found to be deficient based on the level of performance typically observed at a given age.

The present study, which was conducted online, utilized adaptations of existing RFT methods to assess temporal relations. The relational evaluation procedure (REP) is an effective and efficient method to assess various patterns of relational framing (Cassidy et al., 2011, 2016). The REP involves presenting a particular contextual cue (e.g., SAME) in between two or more arbitrary stimuli on the screen (e.g., “QUB is the SAME as TIG”) and asking participants questions about the presented relation (e.g., Is TIG the SAME as QUB?”). Kirsten and Stewart (2022) recently adapted the REP for younger children who were not yet readers or had minimal reading skills by using colored shapes instead of nonsense words and single letters as contextual cues instead of full words, alongside audio options (e.g., [Red circle] [S] [Blue circle] to indicate that “red is the same as blue.”). A similar format was used in the present study as the age of participants was comparable. Additionally, the present study adapted the test for instructional control used by O’Hora and colleagues (2004) to test for a transformation of function effect in accordance with temporal relations. Instead of using computer keyboard presses in an order specified by a relational network, observable and discriminable motor actions were included. We anticipated this as an advantageous modification given the ages of participants and as the study was conducted online.

Method

Participants

Twenty-five typically developing children (13 female, 12 male) between the ages of 3 and 8 years (*M* = 5 years 6 months, *SD* = 17.87 months) participated in the study. These included five 3-year-olds (*M* = 42.49 months, *SD* = 3.63 months), six 4-year-olds-olds (*M* = 56.26 months, *SD* = 3.77 months), four 5-year-olds (*M* = 66.35 months, *SD* = 1.56 months), four 6-year-olds (*M* = 77 months, *SD* = 3.82 months), five 7-year-olds (*M* = 87.92 months, *SD* = 3.23 months), and one 8-year-old (100.5 months). All participants were recruited through personal contacts in the United States and Ireland. Ethical approval for the study was first obtained through the institutional research ethics committee prior to conducting the study. Verbal and written consent was obtained from each participants' caregivers and verbal assent was obtained from the children themselves before starting a session.

Setting and Materials

All sessions took place online through the use of a video conferencing platform with end-to-end encryption. Sessions were conducted at times preferred by each family and with the child and an accompanying family member participating via a networked device in a suitable room in their living residence. All materials were created in Microsoft PowerPoint and displayed on a 13-inch MacBook Pro laptop via the screen-share feature of the video-conferencing platform.

Each child was tested on an initial preassessment and a temporal relations assessment (TRA). The preassessment was used to test the child's ability to vocally label all stimuli used in the TRA, answer yes/no questions, and follow single and multi-step directions. The TRA included two subtests: nonarbitrary temporal relations and arbitrary temporal relations. The nonarbitrary subtest materials included images of eight different common items (e.g., an apple, ball, cat, etc.). The arbitrary subtest included images of four different colored circles (blue, green, red, and yellow), as well as four images of simple motor actions (clapping, raising arm, touching nose, and waving) (see Procedure for complete description of materials used across each test).

Procedure

At the onset of each session, the researcher first tested the audio, video, and screen-sharing features with the participant and their caregiver to ensure all features functioned properly before proceeding. Caregivers were instructed that the purpose of the test was to explore how children would respond to the presented activities and that they as caregivers should not provide answers or guidance to the children at any point during the assessment. Caregivers were asked to intervene only in the event of problems with the audiovisual display. For all test sections, the researcher first waited for participants to demonstrate an observing response (e.g., looking at the screen) prior to beginning the trial. It was determined that if any break in attending to the stimuli occurred (e.g., lag in video call, participant looking away), the researcher would regain the participant's attention by stating their name and asking if they are ready to see the example again before proceeding. Once attending to the stimuli was re-established, the trial presentation for each test section continued as described.

Preassessment

During the first session, children were first administered the preassessment to determine suitability for inclusion in the study. The preassessment included three stages: tacting the stimuli used in the TRA, answering Yes/No questions, and performing simple motor responses. To test for tacting of the TRA materials, the child was shown common items or colors (one stimulus on the screen at a time) and asked by the examiner on each trial, "What is this?" A correct response was scored if the child accurately vocally labelled the stimulus shown on the screen (e.g., said "cat" when an image of a cat was shown). A total of 12 trials was conducted consisting of 8 pictures of common stimuli that were used in the nonarbitrary section of the TRA, and images of 4 colored circles that were used in the arbitrary section of the TRA. The child was then exposed to the same stimuli but tested on their ability to answer Yes/No questions. The examiner showed one stimulus on the screen at a time and asked the child a Yes/No question such as, "Is this an apple?" A total of 12 questions was presented, 6 to which "yes" was the correct response and 6 to which "no" was the correct response.

Following this, children were tested on following single and multi-step instructions with four different motor actions (clap hands, raise arm, touch nose, wave) relevant to the transformation of function section of the TRA. A total of 6 trials was presented, including each of the 4 single actions, 1 probe for two-step actions, and 1 probe for 3-step actions. In the case of each of the individual actions, the child was shown an image on the screen depicting that action and asked to demonstrate it (e.g., "Show me clapping."). A correct response was scored if the child acted out the action specified. If an error occurred, the researcher provided a model of the action and presented another opportunity to correctly perform the action. After each individual action was correctly demonstrated, the child was then asked to perform more than one (i.e., either 2 or 3) of the four actions in succession. A correct response was scored if the child performed each of the actions stated by the examiner but they were not required to perform them in a particular order. In total, the preassessment consisted of 30 individual trials. Participants were required to score 11 out of 12 trials correct on each the tacting and Yes/No sections, and 5 out of 6 trials correct on the motor actions section (total criterion of 27 out 30 trials correct, 90% correct) in order to continue with the study. During initial recruitment, one child did not pass the preassessment and was therefore excluded from the study. All the remaining children (n=25) passed the preassessment.

Temporal Relations Assessment (TRA)

The Temporal Relations Assessment included two major subsections: (i) nonarbitrary temporal relational responding (i.e., responding under the control of physically temporally related events) and (ii) arbitrarily applicable temporal relational responding (i.e., responding under the control of contextual cues that specify temporal relations between events). The assessment was delivered using a combination of visual materials, auditory recordings, and orally presented instructions. For each trial, the particular visual pictures and/or words relevant to answering the question were presented to the participant. Once the materials were displayed, the principal researcher then vocally presented the pre-determined question.

Following completion of the preassessment, children were assessed on the TRA over the course of 1 to 2 sessions that lasted in total between 20-45 minutes per child. Session durations varied depending on breaks given during testing and the age of the child. The TRA was used to test responding to temporal relations at nonarbitrary and arbitrarily applicable levels across a total of 64 trials. Children were first tested on 16 trials of nonarbitrary relations, consisting of 8 questions with 2-image sequences and 8 questions with 3-image sequences. The testing of arbitrarily applicable relations was carried out across 48 trials, consisting of 16 questions for mutual entailment, 16 questions for combinatorial entailment, and 16 questions for transformation of function (8 questions for transformation of function with mutually entailed relations and 8 questions for transformation of function with combinatorial entailment relations). For all trials, each correct response was scored as "1" while an incorrect response was scored as "0."

Throughout all sections of the assessment, no feedback was provided following correct or incorrect responses. In order to maintain engagement, non-specific verbal praise was provided on a schedule of around every four trials (e.g., "you're working really hard"). In between each section, the researcher briefly engaged the participant in conversation about preferred topics unrelated to the test. This was done to maintain a level of rapport and to provide brief breaks between tasks. Additionally, after test sections the researcher asked participants if they would like a brief break before resuming or if they would prefer to continue with the activities.

Nonarbitrary Testing. At the onset of the nonarbitrary section, participants were instructed that they would be shown a series of images and be asked questions about which image came before or after the other(s). Participants were instructed to give a "yes" or "no" vocal response to each question and were told that they could request to see the image sequence again if needed. The 16 trials included both 2-image and 3-image trials and included four trial types. There were 4 "before" trials with "yes" as the correct response, 4 "after" trials with "yes" as the correct response, 4 "before" trials with "no" as the correct response, and 4 "after" trials with "no" as the correct response (Table 3.1). Each of the stimuli used in the nonarbitrary section appeared in all sequential positions and in all trial types (see Appendix A for a full list of the nonarbitrary trials used).

Table 3.1

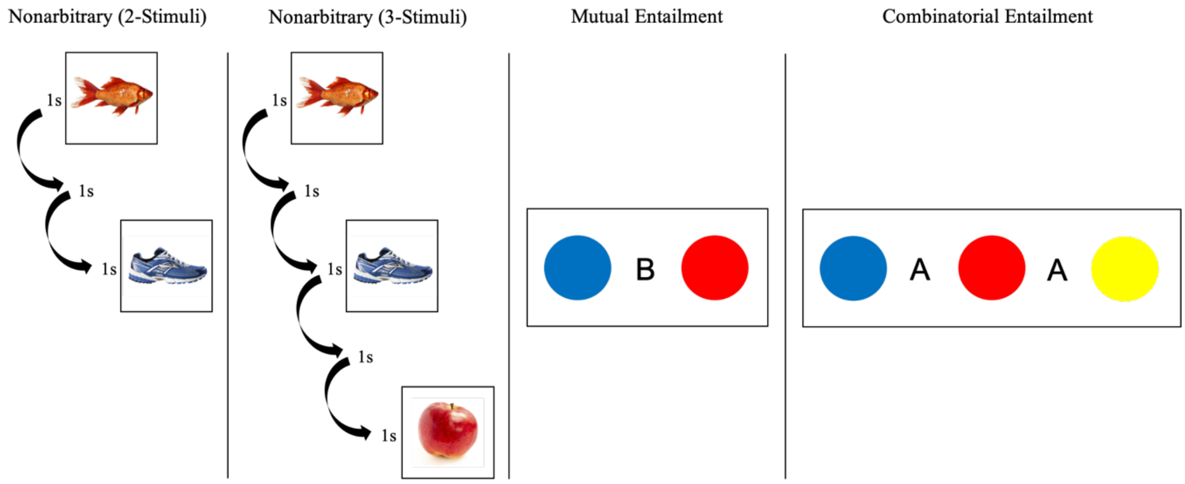
Nonarbitrary Trial Types

Trial	2-Image Sequence			3-Image Sequence		
Type	Observed sequence	Question	Answer	Observed Sequence	Question	Answer
1	A then B	Is A before B?	Yes	A then B then C	Is A before C?	Yes
2		Is B before A?	No		Is C before A?	No
3		Is A after B?	No		Is A after C?	No
4		Is B after A?	Yes		Is C after A?	Yes

In the 2-image nonarbitrary relations trials, a participant was shown a single stimulus (e.g., fish) on the screen for 1s with a simultaneous audio clip producing the name of the item. The image was then removed and a blank screen was shown for 1s, and then a second stimulus was displayed on the screen for 1s (e.g., shoe) again with an accompanying audio clip, and then this second image was removed and a blank screen shown again (Figure 3.1). The experimenter then presented a question regarding the order of the observed sequence using either a "before" or "after" cue (e.g., "Was the shoe before the fish?"). The same procedure was used for trials of 3-image sequences with the only difference being the addition of a third image. That is, an image was shown on the screen for 1s accompanied by an auditory stimulus, followed by a blank screen for 1s, and then a second stimulus appeared for 1s, followed by a blank screen for 1s, and then a third stimulus appeared for 1s, followed by a blank screen (Figure 3.1).

Figure 3.1

Example Stimulus Presentations



Note. From left to right, the figure illustrates an example stimulus arrangement for a two-stimulus nonarbitrary trial, a three-stimulus nonarbitrary trial, a mutual entailment trial, and a combinatorial entailment trial.

Arbitrary Testing: Mutual and Combinatorial Entailment. Prior to beginning the arbitrary relations section, participants were shown sample items of the contextual cues used to indicate "before" and "after" respectively. For all arbitrary trials, the letter "B" was used to cue a "before" relation, and the letter "A" was used to cue an "after" relation. The researcher presented the letter "B" on screen and said, "B means before," and subsequently asked, "What does B mean?" This was repeated by a similar procedure involving the letter "A." Participants were then presented with a sample relational statement for both of the contextual cues. In the case of the "before" cue the researcher showed, for example, [blue circle] [B] [green circle] on the screen and read it aloud to the participant and a similar procedure was conducted in the case of the "after" cue. The researcher then presented two trials in which the participant was asked to read aloud the relational statement (one trial with a "before" cue and one trials with an "after" cue). If participants failed to accurately read aloud the relational statement, the researcher modeled the correct response, reviewed the contextual cues in isolation, and then re-presented a sample relational statement for each contextual cue. Participants had to read aloud the statement accurately on a single-trial probe for each cue before proceeding.

Participants were then tested for arbitrary relations. For all arbitrary trials, the relational statements were presented in a multimodal format as they were both visually displayed on the screen as well as being stated aloud. During trials of mutual entailment, the participant was shown an image consisting of 2 colored circles with a contextual cue in between them (Figure 3.1). An accompanying audio clip was played which stated the relational statement out loud (e.g., "blue is before red"). The researcher then asked the participant a question about the relation between the A-B stimuli (e.g., "Is red after blue?"). Participants were required to give a "yes" or "no" vocal response. During trials of combinatorial entailment, participants were shown an image consisting of 3 colored circles with interspersed contextual cues (Figure 3.1). An audio clip stated the relational statement aloud (e.g., "blue is before red, red is before yellow") and then the researcher asked the participant a question about the A-C relation (e.g., "Is yellow after blue?"). Again, participants had to give a "yes" or "no" vocal response. For both mutual entailment and combinatorial entailment sections, the 16 trials for each section were broken down into 8 unique trial types, examining both directly trained and entailed relations (Table 3.2). Each of the trial types was presented twice as the stimuli were systematically rotated so that they each appeared in all stimulus positions and in all trial types (see Appendix A for a full list of arbitrary trials used).

Table 3.2

Mutual and Combinatorial Entailment Trial Types

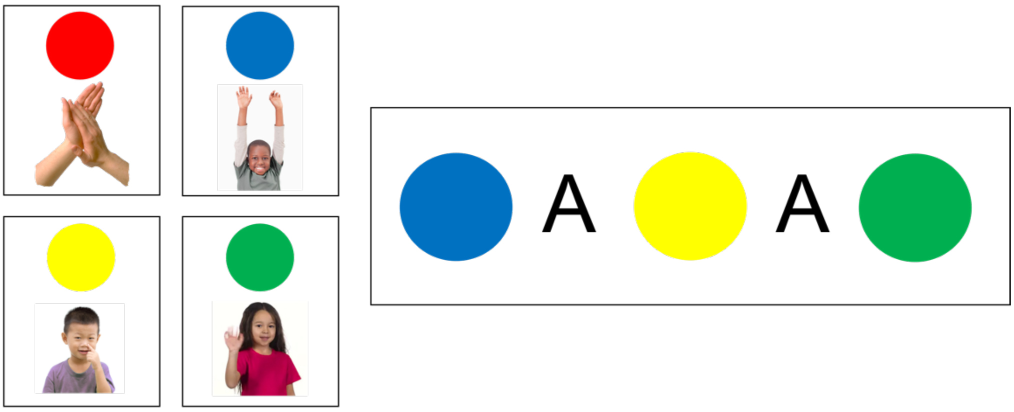
Mutual Entailment			Combinatorial Entailment		
Statement	Question	Answer	Statement	Question	Answer
A before B	Is A before B?	Yes	A before B before C	Is A before C?	Yes
	Is B before A?	No		Is C before A?	No
	Is A after B?	No		Is A after C?	No
	Is B after A?	Yes		Is C after A?	Yes
A after B	Is A before B?	No	A after B after C	Is A before C?	No
	Is B before A?	Yes		Is C before A?	Yes
	Is A after B?	Yes		Is A after C?	Yes
	Is B after A?	No		Is C after A?	No

Arbitrary Testing: Transformation of Function. In order to assess for transformation of function (ToF), the experimenter first trained a discriminative function in each of the arbitrary stimuli. Each of the 4 colored circles was shown one at a time alongside an image of a particular action (clap, raise arm, touch nose, wave). For example, the experimenter showed the red circle, and said, "This means clap," while modeling clapping. Participants were then instructed to copy the action modeled. This was repeated with the other three colors and actions. Subsequently, participants were probed across four trials (i.e., one trial per color) on their ability to demonstrate the correct action when shown the corresponding color. The researcher presented a colored circle on the screen alongside a visual that showed each color-response combination and instructed the participant, "Do this one." Social praise was delivered for correct responding and corrective feedback was used if an incorrect response was emitted. Participants were required to respond correctly to each of the 4 trials before proceeding to ToF testing. If any errors occurred, trials were re-presented until the participant independently demonstrated the corresponding action for each stimulus.

Once the participant had demonstrated each of the stimulus-response combinations correctly, they proceeded to the ToF testing. The 16 ToF trials included 8 mutually entailed ToF trials (ToF-ME) and 8 combinatorially entailed ToF trials (ToF-CE). For all trials, a visual sample was presented on the left side of the screen that showed each color-response combination and the relational statement was presented on the right side of the screen (see Figure 3.2). During the ToF-ME trials, a relational statement with either the "before" or "after" cue (e.g., red before blue) was displayed while an audio clip stated the relational statement out loud. The participant was then told to do the actions in the correct order. If the participant demonstrated the two motor-actions in the order that the relational statement indicated then this was recorded as a correct response. For ToF-CE trials, the same procedure was used with the difference that the relational statement involved 3 stimuli and participants were required to perform 3 motor-actions in the order that corresponded with the relational statement. “Before” cues were used in 8 trials (4 ToF-ME trials and 4 ToF-CE trials) and “after” cues were used in 8 trials (4-ToF ME trials and 4 ToF-CE trials).

Figure 3.2

Example Stimulus Presentation for Transformation of Function Trials



Interobserver Agreement and Procedural Fidelity

Interobserver agreement (IOA) and procedural fidelity data were collected by trained research assistants for 5 of the assessment sessions (20% of participants) for both nonarbitrary and arbitrary relational responding tests. A second observer attended the video conferencing session from a different physical location than either the primary researcher or the participant. IOA was calculated on a trial-by-trial basis for each session and ranged from 94% to 100% (M = 98%). Procedural fidelity for each trial was assessed according to a fidelity checklist and was scored as 100% across observed sessions.

Results

Preassessment

Age cohort results from each section of the preassessment and overall score are shown in Table 3.3. Within the 3-4 years cohort, each participant scored 100% correct on the tacting section. One participant from the 3-4 years group scored 92% correct (11 out of 12 trials) on the Yes/No responding section, and two participants scored 83% correct (5 out of 6 trials) on the motor responses section. All other participants scored 100% correct on all sections of the preassessment.

Correlations

Table 3.4 shows Spearman’s rank correlations between age at the date of testing and scores on the TRA, including total score and subscale scores for nonarbitrary and arbitrary sections.[7] Significant correlations were found between age and total score on the TRA ($r_s = .72, p < .001$), between age and nonarbitrary temporal relational responding ($r_s = .72, p < .001$), and between age and arbitrarily applicable temporal relational responding ($r_s = .64, p < .001$). A significant correlation was

[7] A nonparametric test was employed so as to be conservative given the relatively small sample size involved.

also found between scores on the nonarbitrary and arbitrarily applicable temporal relations subtests (r_s = .77, $p < .001$).

Table 3.3

Age Cohort Mean Scores on the Pre-assessment

Age Cohort	Tact	Yes/No	Motor Actions	Total
3-4 years	100%	98%	93%	98%
4-5 years	100%	100%	100%	100%
5-6 years	100%	100%	100%	100%
6-7 years	100%	100%	100%	100%
≥7 years	100%	100%	100%	100%

Table 3.4

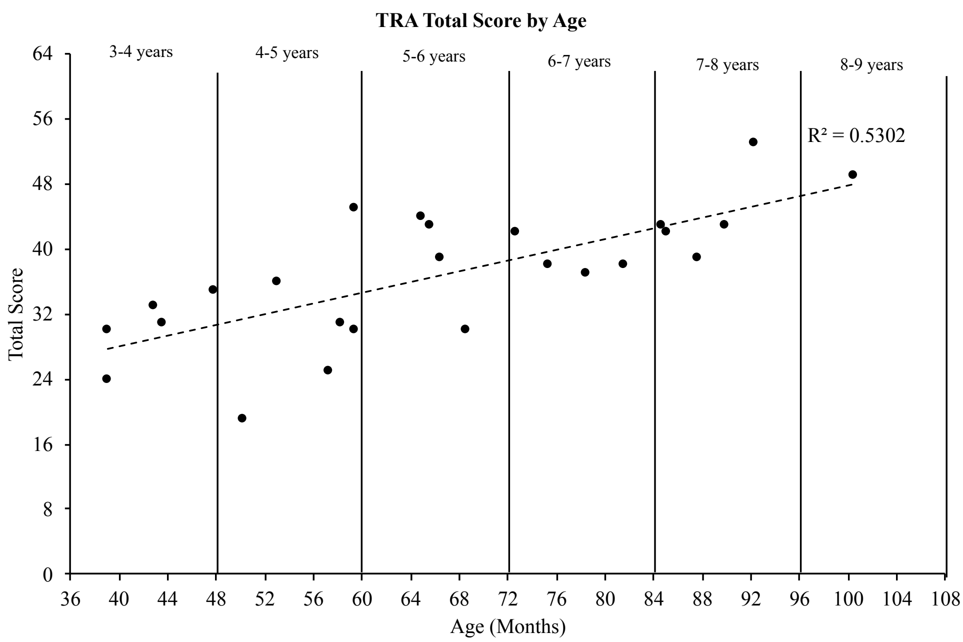
Spearman's Rho Correlations for Age and Temporal Relations Assessment (TRA)

	1	2	3	4
1. Age	--			
2. Total	.722**	--		
3. NARR	.718**	.915**	--	
4. AARR	.644**	.943**	.766**	--

Note. ** Correlation is significant at the 0.01 level (2-tailed). Total = total relational responding score; NARR = nonarbitrary relational responding score; AARR = arbitrary applicable relational responding score

Figure 3.3

Total Scores on the Temporal Relations Assessment (TRA) vs. Age



Relational Responding Scores and Age

Figure 3.3 graphs the correlation between the total score for each participant on the TRA (out of a total of 64 possible points) and age in months. The R^2 value indicates the proportion of variance in total score that can be attributed to age (.53, low to moderate). Note that the 4-5-year-old cohort featured two of the most extreme outliers one of which was 2 standard deviations below the best-fit line. The percentage of correct responses across all sections of the TRA for each participant is shown in Table 5. Total scores on the TRA total assessment ranged from 30% to 83% correct (M = 57%, SD = 8.05). On the nonarbitrary section, scores ranged from 31% to 100% correct (M = 75%, SD = 3.5); on the mutual entailment section, scores ranged from 44% to 81% (M = 61%, SD = 2.20); on the combinatorial entailment section, scores ranged from 31% to 69% (M = 50%, SD = 1.35); and on the transformation of function section, scores ranged from 0% to 100% (M = 44%, SD = 3.58).

Table 3.5 shows the average percentage of correct responses for each cohort both for the TRA as a whole and for each assessment section. The mean scores on the nonarbitrary temporal relations section showed a clear improvement between the youngest and oldest participants (M = 55% to 94% correct, respectively). Performance on the nonarbitrary section was similar for the 3-4 years and 4-5 years cohorts (M = 55% and 58% correct, respectively) but then a substantial improvement is seen in the 5-6 years cohort (M = 80% correct). Performance continued to improve in the 6-7 years (M = 89% correct) and ≥ 7 years cohorts (M = 94% correct). Mean scores on the mutual entailment section also showed a general trend of improvement with age, with the exception of the 6-7 years cohort, who scored the lowest out of any age cohort (M = 53% correct). However, between 3-7 years, group means on the mutual entailment section remained near chance-level responding. For the combinatorial entailment section, no clear improvement with age was apparent and the means for all age groups were near chance-level responding. Mean scores on the ToF-ME and ToF-CE sections each showed improvement between the youngest and oldest participants (M = 38% to 65% correct and 28% to 65% correct, respectively). The 3-4 years and 4-5 years cohorts scored similarly on the ToF-ME section (28% and 29% correct, respectively) and the ToF-CE section (28% and 21% correct, respectively). The 5-6 years and 6-7 years cohorts also scored similarly on the ToF-ME section (56% and 53% correct, respectively) and on the ToF-CE section (47% correct for both cohorts).

Table 3.5

Participants' Scores on the Temporal Relations Assessment (TRA)

ID	M/F	Age (mo)	NARR (%)	ME (%)	CE (%)	ToF-ME (%)	ToF-CE (%)	Total (%)
3-4 years age cohort								
3	F	39	8 (50%)	7 (44%)	9 (56%)	0 (0%)	0 (0%)	24 (38%)
4	M	39	7 (44%)	8 (50%)	8 (50%)	4 (50%)	3 (38%)	30 (47%)
5	M	43	11 (69%)	7 (44%)	7 (44%)	4 (50%)	4 (50%)	33 (52%)
2	M	44	9 (56%)	13 (81%)	5 (31%)	2 (25%)	2 (25%)	31 (48%)
1	F	48	9 (56%)	11 (69%)	8 (50%)	5 (63%)	2 (25%)	35 (55%)
Mean		42.5	8.8 (55%)	9.2 (58%)	7.4 (46%)	3 (38%)	2.2 (28%)	30.6 (48%)
SD		3.63	1.48	2.68	1.52	2	1.48	4.16
4-5 years age cohort								
6	M	50	5 (31%)	6 (38%)	8 (50%)	0 (0%)	0 (0%)	19 (30%)
8	F	53	11 (69%)	9 (56%)	9 (56%)	3 (38%)	4 (50%)	36 (56%)
11	F	57	8 (50%)	8 (50%)	8 (50%)	1 (13%)	0 (0%)	25 (39%)
10	F	58	7 (44%)	10 (63%)	11 (69%)	3 (38%)	0 (0%)	31 (48%)
7	M	59	15 (94%)	14 (88%)	9 (56%)	4 (50%)	3 (38%)	45 (70%)
9	M	59	10 (63%)	8 (50%)	6 (38%)	3 (38%)	3 (38%)	30 (47%)
Mean		56.3	9.3 (58%)	9.2 (58%)	8.5 (53%)	2.3 (29%)	1.7 (21%)	31 (48%)
SD		3.77	3.50	2.71	1.64	1.51	1.86	8.97
5-6 years age cohort								
12	M	65	15 (94%)	12 (75%)	8 (50%)	5 (63%)	4 (50%)	44 (69%)
14	F	66	16 (100%)	10 (63%)	9 (56%)	4 (50%)	4 (50%)	43 (67%)
15	F	66	13 (81%)	9 (56%)	9 (56%)	4 (50%)	4 (50%)	39 (61%)
13	M	69	7 (44%)	10 (63%)	5 (31%)	5 (63%)	3 (38%)	30 (47%)
Mean		66.4	12.8 (80%)	10.3 (64%)	7.8 (48%)	4.5 (56%)	3.8 (47%)	39 (61%)
SD		1.35	4.03	1.26	1.89	0.58	0.5	6.38
6-7 years age cohort								
17	F	73	14 (88%)	10 (63%)	9 (56%)	6 (75%)	3 (38%)	42 (66%)
18	F	75	15 (94%)	7 (44%)	8 (50%)	4 (50%)	4 (50%)	38 (59%)
16	M	78	14 (88%)	9 (56%)	7 (44%)	3 (38%)	4 (50%)	37 (58%)
19	F	82	14 (88%)	8 (50%)	8 (50%)	4 (50%)	4 (50%)	38 (59%)
Mean		77	14.3 (89%)	8.5 (53%)	8 (50%)	4.3 (53%)	3.8 (47%)	38.8 (61%)
SD		3.82	0.50	1.29	0.82	1.26	0.5	2.22
≥7 years age cohort								
22	M	85	15 (94%)	12 (75%)	8 (50%)	4 (50%)	4 (50%)	43 (67%)
24	M	85	15 (94%)	11 (69%)	8 (50%)	4 (50%)	4 (50%)	42 (66%)
23	F	88	13 (81%)	8 (50%)	10 (63%)	4 (50%)	4 (50%)	39 (61%)
21	F	90	16 (100%)	12 (75%)	7 (44%)	4 (50%)	4 (50%)	43 (67%)
20	F	92	16 (100%)	13 (81%)	8 (50%)	8 (100%)	8 (100%)	53 (83%)
25	M	101	15 (94%)	12 (75%)	8 (50%)	7 (88%)	7 (88%)	49 (77%)
Mean		90	15 (94%)	11.3 (71%)	8.2 (51%)	5.2 (65%)	5.2 (65%)	44.8 (70%)
SD		5.89	1.10	1.75	0.98	1.84	1.84	5.15

Age Related Performance across Contextual Cues

An analysis of performance across temporal trial types (i.e., "before" versus "after") was also conducted to further investigate the results found, particularly with respect to the arbitrarily applicable relations sections of the assessment. Figures 3.4-3.6 show the average correct responses per age cohort and relational response type (nonarbitrary, mutually entailed, combinatorially entailed, and transformation of function) based on the contextual cue used (i.e., "before" versus "after"). The NARR data in Figure 4 refer to which word was used in the question for that section of the assessment. For mutual entailment, combinatorial entailment, and transformation of function, the "before" data in Figures 5 and 6 represent trials in which the relational statement read, "A before B" and "A before B before C" (see trial types in top half of Table 3.2). "After" data represent trials in which the relational statement read, "A after B" and "A after B after C" (see trial types in bottom half of Table 3.2).

For the nonarbitrary-2 stimuli section (Figure 3.4), the 3-4-year-old cohort responded with slightly higher accuracy on "before" trials compared to "after" (M = 60% and 63% correct, respectively) as did the 4-5-year-old cohort (55% and 50% correct, respectively). The 5-6-year-old cohort however, performed with higher accuracy on "after" trials (M = 81% correct) compared to "before" trials (M = 63% correct). The mean scores for the 6-7-year-old cohort were the same across both trial types (M = 94% correct), while the ≥ 7-year-old cohort scored higher on "before" compared to "after" trials (M = 100% and 92% correct, respectively). For the nonarbitrary-3 stimuli section (Figure 4), the 3-4-year-old cohort scored higher on "after" trials (M = 55% correct) compared to "before" (M = 50% correct). The 4-5-year-old cohort performed better on "before" trials (M = 67% correct) compared to "after" trials (M = 54% correct). The mean scores for the 5-6-year-old cohort were the same across both trial types (M = 88% correct). The 6-7-year-old group performed slightly better on "before" trials than "after" (M = 88% and 81% correct, respectively) as did the ≥ 7-year old-group (M = 96% and 88% correct, respectively).

On the mutual entailment section (Figure 3.5), there was an improvement on "before" trials with age with the exception of the very oldest group (M = 60%, 71%, 78%, 91% 77% correct, respectively moving from youngest to oldest). On "after" trials performance remained near chance level responding in the three youngest age groups (55%, 44%, and 50% correct, respectively) but then in the 6-7-year-old cohort the mean scores were substantially lower than had been the case for the previous three groups (M = 16%) and then performance for the oldest cohort was the highest among the cohorts (M = 65%). As regards a comparison between performance on "before" and "after" it might be noted that difference in mean scores across "before" and "after" mutual entailment trials became increasingly pronounced from the 3-4-year-old cohort to the 6-7-year-old cohort.

As regards combinatorial entailment (Figure 3.5), performance on "before" trials was lowest in the 3-4-year-old group (48% correct) and somewhat better in the 4-5 and 5-6-year-old groups (67% and 63%, respectively). The two oldest cohorts both showed high levels of correct responding on "before" trials, with the 6-7-year-olds performing better (*M* = 97%) than the ≥ 7 years group (*M* = 81%). In contrast, performance on "after" trials showed a gradual disimprovement with age moving from the 3-4 to the 5-6-year-old cohorts (*M* = 45%, 40%, 34% respectively) before showing a much lower performance from the 6-7-year-old age group (3% correct) and then a slight increase again in the oldest cohort (21% correct). As in the case of mutual entailment trials, the difference in mean scores on "before" and "after" trials became increasingly pronounced between the 3-4-years group up to the 6-7-years group.

Results on both transformation of function trial types (ToF-ME and ToF-CE; Figure 3.6) show that the participants 5 years and older demonstrated high levels of accuracy with "before" trials while mean scores on "after" trials for the transformation of function sections remained low across all age cohorts. It is noted that only two participants (P20 and P25 who were both in the ≥ 7 years group) scored high on the "after" trials in the transformation of function sections (100% and 75% correct, respectively).

Figure 3.4

Average Percentage Correct per Age Cohort on Nonarbitrary Relational Responding (NARR) Trials

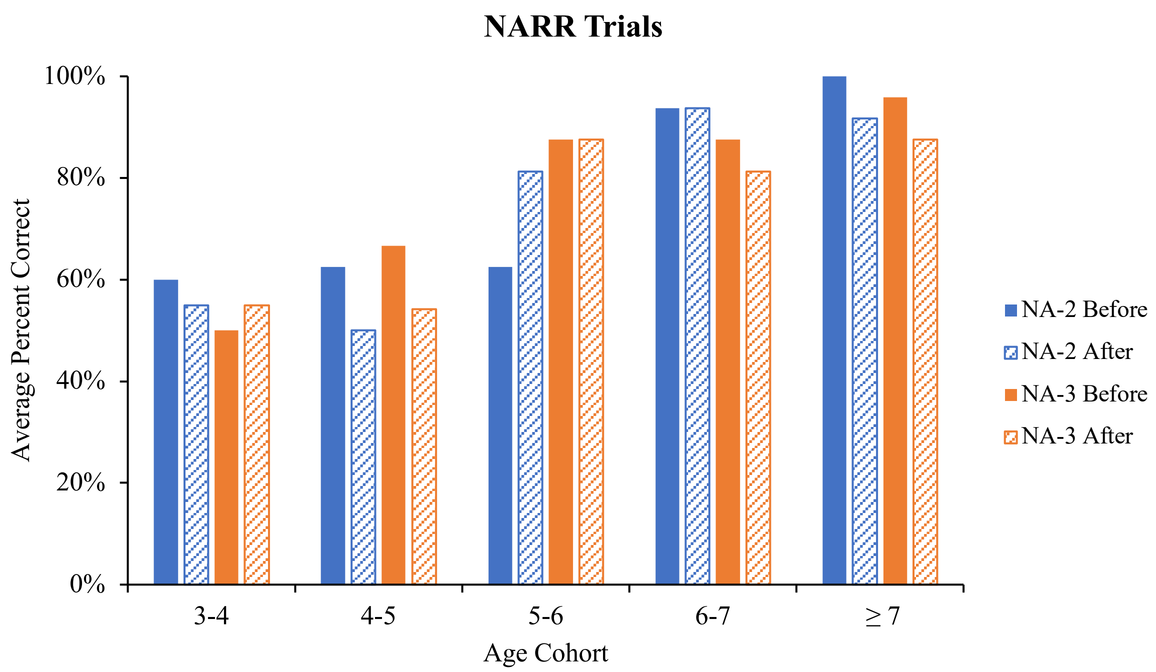


Figure 3.5

Average Percentage Correct per Age Group on Mutual Entailment and Combinatorial Entailment Trials

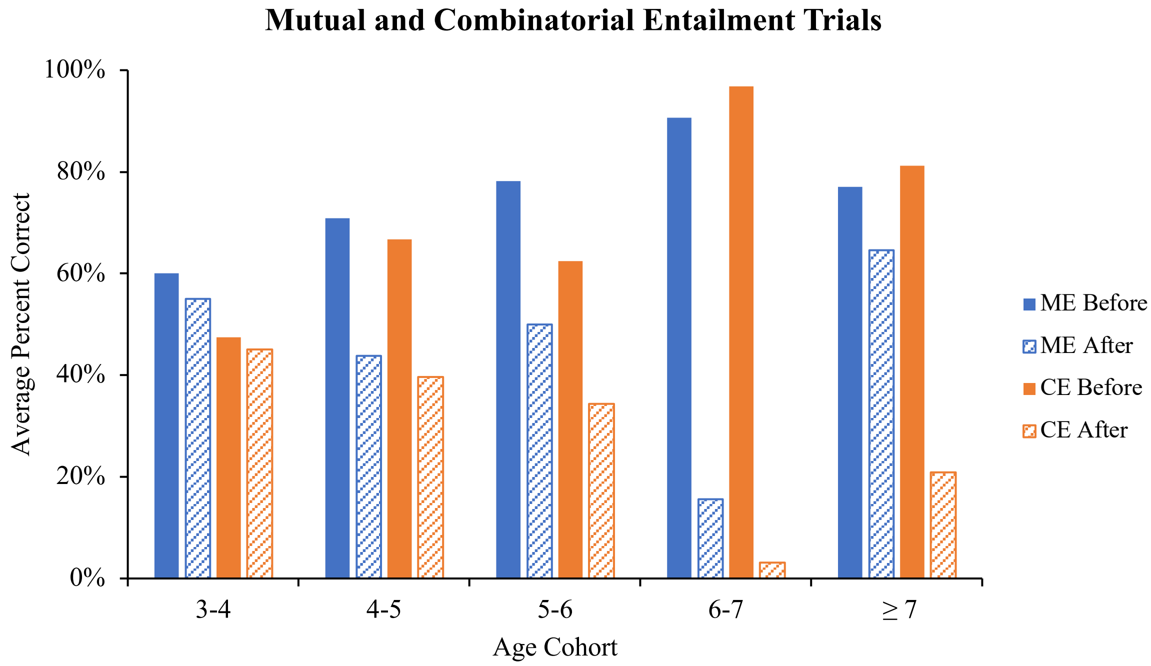
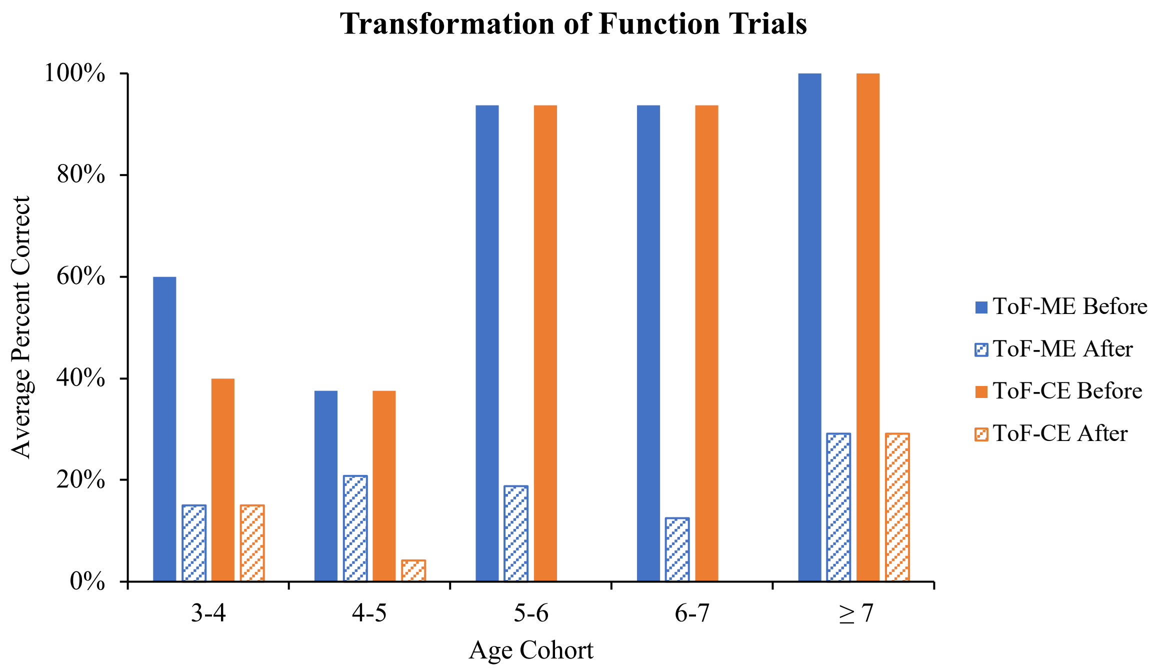


Figure 3.6

Average Percentage Correct per Age Group on Transformation of Function Trials



Discussion

The present study aimed to examine the development of temporal relational responding in young children across a range of ages. Specifically, children between 3 and 8 years of age were tested on an assessment of nonarbitrary and arbitrary temporal relations. To date, RFT research has minimally investigated temporal relational frames and the research that has been done has primarily investigated this repertoire in adults with an existing repertoire.

The present study expands on prior RFT research in this area and provides new empirical data on the acquisition of temporal relational responding patterns in children. Overall performance on the TRA was shown to increase with age. Significant correlations were found between age and total score on the assessment as well as between age and performance on both the nonarbitrary and arbitrary relations sections. Performance on the nonarbitrary temporal relations section steadily increased with age as average scores for each age group tended to be higher than for younger groups. Children 5 years and older in particular showed high levels of responding on nonarbitrary trials. Other patterns were observed on the arbitrary relations section, which included trials for mutual entailment, combinatorial entailment, and transformation of function. Performance on mutual entailment and transformation of function trials generally increased between the youngest and oldest participants, though errors were still made by the oldest participants. Accuracy on combinatorial entailment trials did not appear to improve with age as all cohorts performed near chance level responding. However, when analyzed according to trial types, notable differences in performance between "before" and "after" trials were observed (Figures 3.4-3.6). This pattern will be elaborated on below.

One key finding from the present study was that different patterns were observed across ages when comparing responding in accordance with nonarbitrary temporal relations and responding in accordance with arbitrary temporal relations. Namely, with the nonarbitrary section of the assessment, accuracy on "before" and "after" questions improved similarly with age (see Figure 3.4). However, on arbitrary sections of the assessment, better accuracy was consistently observed across all ages on trials that included "before" as the cue for the trained relation compared to trials that included "after" as the cue for the trained relation (see Figures 3.5 and 3.6). For example, trials that showed a relational statement such as, "red before blue" and included questions like, "Is blue before red?" or "Is blue after red?" were on average responded to with greater accuracy than trials that showed a relational statement such as, "green after yellow" with questions like, "Is green before yellow?" or "Is green after yellow?"

While performance on arbitrary trials with "before" as the trained contextual cue generally improved with age, the pattern of performance on arbitrary trials with "after" as the trained contextual cue was more complex. For the mutual entailment section, mean scores on "after" trials remained around chance level responding between 3-6 years. A substantial drop in mean accuracy on these trials was observed in the 6-7-year-old cohort (M = 16% correct) followed by a substantial improvement to the highest-level performance of any cohort in the ≥ 7-year-old group (M = 65% correct). For the combinatorial entailment section, a somewhat similar pattern was observed for the younger age groups to the extent that the 3-6-year-olds showed low levels of correct responding, and the 6-7-year-olds again showed a substantial drop in correct responding (M = 3% correct) compared to the 3-6-year-olds. However, in this case while the oldest cohort did show an increase in mean accuracy (*M* = 21% correct) compared to the 6-7-year-old group their level of performance remained low. For transformation of function trials, children 5 years and older demonstrated high levels of accuracy with "before" trials but all ages had low levels of accuracy on "after" trials.

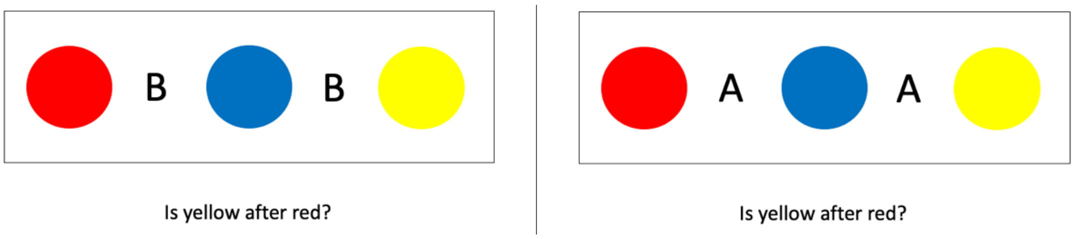
These results suggest firstly that trials in which "after" was the stated relation were more challenging than trials in which "before" was the stated relation across all arbitrary sections. This coheres with previous work with adults which also found that participants tended to respond slower and with less accuracy with "after" relations (Brassil et al., 2019; Hyland et al., 2012, 2014; McGreal et al., 2016). One possible reason for why both children and adults might be less accurate with "after" than "before" relations is as follows. Temporal framing is acquired gradually, as with all frames. Particularly, there may be functionally different aspects of the relational pattern to be acquired. Children might learn "before" prior to learning "after," or more generally, children may receive more exposure to "before" relations than "after" relations. It is also plausible that children receive more practice deriving an entailed "after" relation based on "before" than vice versa. Further research is suggested to investigate potential differences between the acquisition of these contextual cues in children.

One specific issue affecting the acquisition of temporal relational responding that might contribute to differential performance with respect to "before" and "after" contextual control (and one previously hinted at in cognitive developmental research by Clark, 1971) is the potential of a conflict between a nonarbitrary temporal relation controlling the response and the arbitrary temporal relation controlled by the contextual cue. For instance, when a participant was told the trained relation, "red is before blue, blue is before yellow," the experienced temporal order of the stimuli in terms of what was heard auditorily (and possibly observed visually) was "red"…"blue"…"yellow." This experienced sequence coheres with the stated arbitrary temporal relation. However, when told, "red is after blue, blue is after yellow," the experienced sequence is the same but in this case, the arbitrary relation conflicts with the nonarbitrary relation. Previous RFT research has shown that such conflicts can lower levels of correct derivation of the arbitrary relation (Kenny, Barnes-Holmes, et al., 2014; Kenny, Devlin, et al., 2014; Stewart et al., 2002).

If the relational statement is presented visually then the same potential issue arises but in that case there is also a spatial dimension involved. To illustrate, Figure 3.7 below shows relational statements with both "before" and "after" contextual cues with the added question, "Is yellow after red?" With the "before" relational statement, a person may correctly derive that yellow is after red based purely on the arbitrary cue, or they might also relate yellow as after red based on the spatial relation of left-to-right (because yellow is further to the right of red). Either way, there is congruence between the temporal order according to the contextual cue and the spatial order. This congruence is not the case when "after" cues are used in a statement. For example, in Figure 7 on the right side, a person may correctly derive that red is after yellow if they respond in accordance with the arbitrary contextual cue. If, however, they are responding in accordance with a spatial relation of left-to-right, they will answer this question as though yellow is after red (because yellow is further to the right of red). In other words, there is incongruence between the order based on the arbitrary contextual cue and the spatial order.

Figure 3.7

Comparison of Relational Statements Using "Before" and "After" Contextual Cues



An interaction between spatial and temporal relations may be sensitive to one's individual reinforcement history. For instance, while terms like "before" and "after" are often used for temporal relations, they are also used for spatial relations. Barnes-Holmes and colleagues (2001) suggested that young children's misuse of prepositions (e.g., "can I have any reading *behind* dinner," Pinker, 1990) might be explained by children initially developing more general relational frames, which are then shaped to be more specific through interactions in the verbal community. Prepositions for temporal and spatial relations in particular bear similarity and may initially participate in a more general frame before they are acquired as contextual cues for distinct temporal and spatial relations.

In English-speaking socioverbal communities, people read from left-to-right and children are typically taught to sequence items from left-to-right, thereby possibly establishing a learning history that stimuli to the left may come "before" stimuli to the right. Indeed, some recent work has shown that a directional preference (e.g., left-to-right) for ordering events gradually emerges in childhood (Tillman et al., 2022; 2018). This too is arbitrary as a left-to-right order is based on social convention, and research from other domains has showed humans spatially represent time in other ways such as right-to-left (Fuhrman & Boroditsky, 2010) top-to-bottom (Boroditsky, 2001) and even according to cardinal directions like east-to-west (Boroditsky & Gaby, 2010). Further, research has shown that people can be trained to spatially represent time in different ways (Hendricks & Boroditsky, 2017). Nevertheless, if a history of reinforcement is established for reading or ordering from left-to-right, then it is likely the person will actually experience the stimuli in this order in a nonarbitrary sense. This means that they may orient to the image on the left first, and then scan towards the right. Correctly answering "after" trials is potentially more difficult, as the arbitrary temporal relation is incongruent with how the stimuli are experienced nonarbitrarily if reading from left-to-right.

If a person were to respond in this manner (based on the spatial-order), this would likely produce a response pattern where questions that involve stimulus arrangements like that on the left of Figure 3.7 are answered correctly and stimulus arrangements like that on the right of Figure 7 are answered incorrectly. That is, a child could score 50% correct on all arbitrary trials by responding to the spatial order of presentation without using the “before” and “after” cues. Accordingly, the relational response may be under stimulus control of an observed spatial relation instead of under the control of the contextual cue. Additionally, the same pattern would occur on a transformation of function trial. If relating the stimuli based on a spatial relation (i.e., further left is “before” and further right is “after”), a person may act out the actions in sequence based on the colors from left-to-right regardless of the arbitrary cue presented. Indeed, participants 5 years and older showed high levels of accuracy to ToF “before” trials, while nearly all failed the “after” trials. As an anecdotal example, P12 accurately read aloud the relational statement during ToF trials, (i.e., vocally stated that "blue is after green") yet performed the actions according to the spatial left-to-right order (blue...then green).

Apart from the difference in performance on “before” and “after” trials one other interesting aspect of the current data is the decrement in performance on “after” trials in the 6-7-year-old group in particular compared to the younger groups. For the ME trials this substantial drop in performance for the latter cohort is juxtaposed with a significant improvement in the oldest cohort. In the CE trials there is a similar drop in performance in the 6-7-year-olds that again is followed by an improvement in the oldest group, though in the case of the CE trials this improvement was not a substantial one. One possible explanation for this pattern is that the youngest groups are simply guessing (as evidenced by the fact that they are showing a correct rate of around 50%) whereas the 6-7-year-olds are responding systematically but under the wrong stimulus control. More specifically, it might be that they are in fact responding under the pattern of stimulus control discussed in the previous paragraphs. For example, if participants were responding on “after” trials not in accordance with the arbitrarily applicable temporal relation but in accordance with the nonarbitrary relation between the stimuli in the trained statement (whether temporal or spatial) then they would get zero or close to zero correct. In contrast, the obvious improvement in performance on ME “after” trials in the oldest cohort could be due to the fact they have by now acquired the repertoire of appropriate derivation in accordance with temporal ME and this overrides to some extent potential influence by nonarbitrary relations. In the case of the CE relations even the oldest cohort did not show correct responding for “after” relations, suggesting that in this case this cohort had yet to acquire this repertoire.

The present study adds to the body of RFT research more broadly in a number of ways. It expands work on temporal relations to a new population and provides data for the development of temporal framing in children. It expands on the results by Kirsten and Stewart (2021) relative to temporal frames by assessing this frame more specifically and adding a test for transformation of function with temporal relations. The test for transformation of function was adapted from O’Hora et al. (2004) and provides an initial approach to assessing this relational frame property with temporal relations in children. As has been discussed, the current work also highlights potential key differences in the acquisition of “before” vs “after” with respect to contextual control. Finally, a secondary benefit of the present study is that the relational assessment was carried out entirely online. As the use of online learning models continues to grow, future RFT research may find utility in further exploring online formats (e.g., synchronous, asynchronous) for testing and training of relational skills in children.

The present data also provides new insight on non-RFT based research on “before” and “after” comprehension in children. Research on the comprehension of “before” and “after” has historically been limited to examining how their placement in a sentence affects performance. The present study however, sought to examine these terms in the context of contextual control over relational responding (both nonarbitrary and arbitrary). From an RFT view, the cognitive developmental or linguistic studies that involve answering questions about observed actions coming “before” or “after” others (Blything et al., 2015; McCormack & Hanley, 2011) are likely assessing responding under the control of nonarbitrary relations, whereas studies involving questionnaires or hypothetical scenarios rely on AARR (Pyykkönen & Järvikivi, 2012). Distinguishing between NARR and AAAR offers new insight on the acquisition of temporal understanding in children as the primary source of stimulus control over temporal NARR is the actual experience of sequential change, while temporal AARR is under control of the contextual cue itself. In the present study, the NARR data indicated that performance with both terms similarly improved with age. The AARR data however, showed that deriving temporal relations in the presence of “before” cues was more strongly established in participants than deriving temporal relations in the presence of “after” cues.

There are a number of limitations of the current study that could be addressed in future research. First, this study did not include any norm-referenced measures of cognitive or language abilities to which performance on the TRA could be compared. Other RFT studies have shown strong correlations between performance on relational tasks and standardized measures of cognitive or language abilities (Kent et al., 2017; Kirsten & Stewart, 2022; Mulhern et al., 2017). By including similar measures in future work, this line of research could be extended specifically to temporal relations with children.

A second consideration is the relatively small sample size and relatively limited range of participant ages in the present study. Using a larger sample across all age cohorts would improve the external validity of results and might provide further insight into developmental patterns. In addition to the size of the sample, future research should also look at expanding the assessment to older age groups. While overall performance on the temporal relations improved with age, error patterns with arbitrary relations were still present in the oldest participants within the present study. As previously mentioned, even adults show some differences between derivations based on “after” versus “before” relations. Conducting this assessment with a wider age range might help to further clarify at what age(s) children might begin to more reliably demonstrate mastery of these types of relational tasks.

Another consideration for future research is to address the relatively limited trial types used. In the present study, only yes/no questions were used for the nonarbitrary, mutual entailment, and combinatorial entailment sections. Future research might include additional response topographies, such as tacting the correct contextual cue on trials or selection-based responses to more fully examine the relational repertoires. Secondly, the nonarbitrary section used only short (1s) durations between stimuli. Future work could present questions of nonarbitrary temporal relations with events that happened over a longer time frame (e.g., a few minutes ago). Additionally, the current study exclusively used multimodal relational statements (i.e., participants saw the relational statement while hearing it spoken aloud). It remains unclear to what extent each of these modalities might have facilitated performance. Future work might compare performance across visual, auditory, or multimodal presentations of relational statements.

The present study also included different stimuli across test sections with more concrete stimuli used on nonarbitrary trials and only colored shapes on arbitrary trials. Concrete stimuli were selected for the nonarbitrary trials to provide more salient exemplars and a clearer discrimination between stimuli within and across trials since the task involved the presentation/removal of stimuli. The use of colored shapes for the arbitrary trials was however adopted from recent empirical work using this REP format (Kirsten & Stewart, 2022; Kirsten et al., 2022a, 2022b). We suggest that future research utilize the same stimuli across both nonarbitrary and arbitrary tasks, whether it be more meaningful or abstract stimuli. Further, the present study only used contextual cues between the relata ("A before B"; "B after A") to be consistent with the REP format. However, in natural environments, these cues may also be contacted in the first part of sentences (e.g. "Before B, A"; "After A, B"). As previously noted, other psychological research has showed performance differences with these arrangements in children (McCormack & Hanley, 2011) and this could be evaluated from an RFT perspective.

Additionally, only "before" and "after" cues were used to assess nonarbitrary and arbitrary temporal relations. While these two words are important to contextually controlled temporal relational responding, investigating performance with additional words might be desirable to closer examine the flexibility, fluency, and breadth of the relational repertoire (Luciano et al., 2009). Words like "first" and "last" are other commonly used words to which young children may often be exposed. Some linguistic research has shown that young children may more easily follow instructions with "first" and "last" (e.g., "Move the red car first; move the blue car last,") compared to "before" and "after" ("Move the red car before you move the blue car) due to the absence of a subordinate clause (Amidon & Carey, 1972). In the present study, "before" and "after" were specifically selected because they advantageously describe a relation between stimuli in a manner similar to that seen in other RFT studies on relational framing, whereas "first" and "last" more so describe a feature of a stimulus or deal with quantification of the (temporal) dimension. Nonetheless, these terms could be used for example, by giving a relational context (e.g., "if A is after B and B is after C…") and assessing for a transformation of ordinal functions using “first” and “last” (“…Which is first/last?”). Other types of temporal relations could also be examined by using experienced past events (“Which was a longer time ago, your birthday or Christmas?”) or hypothetical future events (“Which comes sooner, your birthday or Christmas?”). Future research might integrate these terms as well as other commonly used words into protocols of assessment and training of temporal relational responding.

Based on the present results, future research might seek to investigate the relationship between cues for spatial and temporal relations further as time is often represented spatially. In the present study, visual stimuli were presented horizontally and read from left-to-right. As previously discussed, notable differences in performance were observed between the arbitrary temporal contextual statements in the current study. For instance, did the participants that responded correctly to “after” trials (such as those to the right in Figure 3.7) respond under control of the contextual cue for a temporal relation or might they have responded based primarily on a reversed spatial relation? In other words, was a rule derived about the spatial order (e.g., right-to-left order) which thereby altered responding? More investigation is needed to examine to what extent arbitrary spatial relations might interfere or compete with stimulus control under the temporal contextual cues in children.

A final recommended research direction is to examine training procedures for temporal relational responding. The aim of the present study was to explore how children at different ages perform with relational tasks when assessed and did not include a specific training component. One direction might be to investigate directly training both temporal NARR or AARR repertoires directly. For instance, the current study found that deriving arbitrary relations when given an “after” cue to be particularly difficult for participants. Future research could look to train this skill in particular. Another direction might consider to what extent training a temporal NARR repertoire facilitates acquisition of temporal AARR. In the current study, the NARR repertoire appeared to hit mastery prior to the AARR repertoire (which in fact with respect to some specific patterns was not seen in any of the cohorts) and they strongly correlated with each other. RFT research on other relations has shown that NARR is an important precursor ability to AARR and may help support the acquisition of particular relational frames (Berens & Hayes, 2007). Similarly, another direction could be to examine whether training other particular frames help facilitate the acquisition of temporal framing. Investigating further which relational repertoires are important precursors could help pinpoint optimal relational training sequences that involve temporal relations.

Conclusion

Despite the limitations, the present study provides insight into children’s performance on tasks of nonarbitrary and arbitrary temporal relational responding. The current data expands the research base on temporal frames to a new population and adds to the growing RFT literature on relational responding abilities more generally. The results can be used as a starting point for further investigation into how contextual control is acquired for temporal relations and how these repertoires may be best trained in children.

Chapter 4.

Developing Procedures for Training Temporal Relational Responding in Children

Existing research on temporal skill sets—and more specifically temporal relational responding—has minimally investigated the environmental variables that influence the acquisition of temporal understanding. While some research has shown that feedback and other instructional arrangements can improve understanding of temporal order in sentences (Amidon & Carey, 1972; Ehri & Galanis, 1980), studies are largely descriptive in nature. Turning towards a behavioral approach may assist with addressing this limitation on training these skills due to an emphasis on both prediction and influence of behavior (Biglan & Hayes, 1996). One particularly relevant approach in this regard is relational frame theory (RFT; Hayes, Barnes-Holmes, et al., 2001; Stewart, 2016), a contextual behavior analytic account of human language and cognition. Substantial empirical research now attests to the efficacy of RFT as a basis for teaching basic and complex language skills to children and adults with and without disabilities (Gilroy et al., 2015; Kirsten et al., 2022a; Ming et al., 2018; Newsome et al., 2014; M. O'Connor et al., 2017; Tarbox et al., 2011; Wymer et al., 2016)

RFT research has also developed methods that can be used to *predict* behavior (e.g., the Implicit Relational Assessment Procedure, Hughes & Barnes-Holmes, 2013; Kelly & Barnes-Holmes, 2013). Indeed, one aim of the previous study in Chapter 3 was to provide initial data on how we might generally expect a child to respond at a given age on tasks of temporal relational responding. Critically, however, an important implication of derived relational responding being a form of generalized operant behavior is that it can be specifically taught. As such, an RFT approach can also be used to *influence* behavior—a central component of the scientific goal of a functional contextual perspective. Since AARR can both be established and strengthened, the procedures used to develop this skill can be studied to identify effective ways of influencing behavior (Barnes-Holmes, Barnes-Holmes, & McHugh, 2004; Barron et al., 2019; Berens & Hayes, 2007; Dunne et al., 2014; Gilroy et al., 2015; Ming et al., 2018; Mulhern et al., 2018; Rehfeldt & Root, 2005). As such, this goal of predicting and influencing behavior, can be applied specifically to training derived temporal relations.

From an RFT view, the acquisition of relational responses is not happen-stance or the product of a developmental stage. Similar learning contexts that often happen in natural interactions can be created and used in a systematic way to teach AARR to children. One such teaching approach that has successfully been used is multiple exemplar training (MET; Barnes-Holmes, Barnes-Holmes, et al., 2004). The use of MET has been shown to be an effective strategy to establish arbitrarily applicable relational responding in children in the presence of contextual cues for coordination (Rehfeldt & Root, 2005), distinction (Dunne et al., 2014), comparison (Berens & Hayes, 2007), opposition (Barnes-Holmes, Barnes-Holmes, et al., 2004), hierarchy (Ming et al., 2018), and advanced frames such as deixis (Gilroy et al., 2015) and analogy (Carpentier et al., 2002).

Applying MET to relational skills involves rotating a variety of stimuli while keeping the targeted contextual cues the same. With temporal relations, training could for instance involve varying stimuli used alongside the specific contextual cues "before" and "after." Across a range of exemplars, a learner is reinforced for responding consistent with the relational pattern and provided error correction as necessary. Once criterion is reached with one set, the learner is then exposed to a novel set of stimuli and tested for relational responding in the absence of reinforcement procedures.

No work has thus far investigated the training of temporal relations in young children. The aim of the present study is to pilot the efficacy of a MET protocol based on RFT to train temporal relational responding in young children. Specifically, the present study sought to train mutually and combinatorially entailed temporal relations with "before" and "after" cues.

Method

Participants and Setting

Three children agreed to participation and two were included in the study. P1 was a female aged 6 years and P2 was male aged 6 years. Both participants were typically developing and attend schools in the west of Ireland. Participants at this age were recruited based on their performance on a previously administered test of temporal relations (Neufeld et al., 2023). Each participant demonstrated high accuracy on nonarbitrary temporal relations tasks but not with arbitrary temporal relations tasks. A third child was omitted from the study due to passing mastery criterion on baseline probes. Ethical approval for recruitment of participants was first obtained from the research ethics committee at the host institution of the lead researcher. Parental consent for participation was obtained for both children and verbal assent was obtained from each child participant.

All sessions were held online through a video conferencing platform with end-to-end encryption (Zoom). Sessions were held at convenient times during the day for both families via a networked device in their household. All probe and training were administered by the primary researcher. Prior to beginning each session, an accompanying family member was present to assist with ensuring all audio and visual features functioned properly. At the onset of a session, the accompanying family did not remain on-screen but remained in a nearby room in their home. All sessions were held up to 3 times per week, with each session lasting between 15-20 minutes.

Experimental Design

A combination noncurrent multiple baseline design across participants and a multiple probe design across responses was used for the current study. Prior to sessions, participants were preassigned to a baseline length of 3 or 5 sessions. Predetermined baselines were used in order to improve the internal validity of the nonconcurrent design (Christ, 2007; Watson & Workman, 1981).

Materials

Session materials were displayed on a 13-inch MacBook Pro running Microsoft PowerPoint via the screen-share feature of Zoom. The materials used for probe or training sessions included sets of images of common stimuli. Four different stimulus sets were included, with each set including 4 unique stimuli (see table 4.1). During intervention sessions, tokens were used via ClassDojo in which a virtual avatar was administered points.

Table 4.1

Multiple Exemplar Training (MET) Stimulus Sets

Set 1	Set 2	Set 3	Set 4
Red	Cat	Square	Apple
Blue	Bird	Circle	Banana
Yellow	Fish	Star	Pizza
Green	Pig	Triangle	Ice cream

Measurement

Accuracy of responding was measured on first trial probes across each trial-type for both mutually entailed responses and combinatorial entailment responses. Each trial type is shown below in Table 4.2. For each trial, a response was scored as correct if the participant gave a "yes" vocal response when the answer was yes, or a "no" vocal response when the answer was no. Scores were totaled out of 16 and then converted to a percentage for both mutual entailment and combinatorial entailment trials.

Table 4.2

Mutual and Combinatorial Entailment Trial Types

Relational Level	Trial Type	Relational Statement	Question	Answer
Mutual Entailment	1	A1 before B1	Is A1 before B1?	Yes
	2	A2 before B2	Is B2 before A2?	No
	3	A3 before B3	Is A3 after B3?	No
	4	A4 before B4	Is B4 after A4?	Yes
	5	B1 before A1	Is A1 before B1?	No
	6	B2 before A2	Is B2 before A2?	Yes
	7	B3 before A3	Is A3 after B3?	Yes
	8	B4 before A4	Is B4 after A4?	No
	9	A1 after B1	Is A1 before B1?	No
	10	A2 after B2	Is B2 before A2?	Yes
	11	A3 after B3	Is A3 after B3?	Yes
	12	A4 after B4	Is B4 after A4?	No
	13	B1 after A1	Is A1 before B1?	Yes
	14	B2 after A2	Is B2 before A2?	No
	15	B3 after A3	Is A3 after B3?	No
	16	B4 after A4	Is B4 after A4?	Yes
Combinatorial Entailment	1	A1 before B1 before C1	Is A1 before C1?	Yes
	2	A2 before B2 before C2	Is C2 before A2?	No
	3	A3 before B3 before C3	Is A3 after C3?	No
	4	A4 before B4 before C4	Is C4 after A4?	Yes

5	C1 before B1 before A1	Is A1 before C1?	No
6	C2 before B2 before A2	Is C2 before A2?	Yes
7	C3 before B3 before A3	Is A3 after C3?	Yes
8	C4 before B4 before A4	Is C4 after A4?	No
9	A1 after B1 before C1	Is A1 before C1?	No
10	A2 after B2 after C2	Is C2 before A2?	Yes
11	A3 after B3 after C3	Is A3 after C3?	Yes
12	A4 after B4 after C4	Is C4 after A4?	No
13	C1 after B1 after A1	Is A1 before C1?	Yes
14	C2 after B2 after A2	Is C2 before A2?	No
15	C3 after B3 after A3	Is A3 after C3?	No
16	C4 after B4 after A4	Is C4 after A4?	Yes

Procedure

Baseline

For all baseline sessions, participants were exposed to each of the 16 mutual entailment trials, followed by each of the 16 combinatorial entailment trials, for a total of 32 trials per session. During each baseline session, one of the relational statements was presented on the screen (see Table 4.2). The researcher then read aloud the presented relational statement (e.g., "Square is before star") and subsequently asked the participant a question about the relation (e.g., "Is star after square?"). Once the participant responded, the screen was changed to the next trial and the procedure repeated until all trials were presented. During baseline, no reinforcement was provided for correct responses and no error-correction was provided for incorrect responses. A session ended once each of the trials type had been presented.

Intervention

Following baseline, participants were exposed to training on mutually entailed relations with only one of the four stimulus sets with each of the 16 different trial types. The presentation of each trial was identical to the baseline condition, apart from programmed consequences for responses. During training, correct responses were reinforced on a continuous schedule of reinforcement (FR1) with specific verbal praise (e.g., "Nicely done! [A] is after [B]!"). and token delivery. Tokens were administered in the form of points, which were given to a virtual avatar selected by the participant in ClassDojo that was visible to the participant via screenshare. Tokens were then able to be exchanged for preferred activity such as a video or game once the session goal criterion was met (Berens & Hayes, 2007; Mulhern et al., 2018). For each session, a goal criterion was designated based on performance from the previous session (e.g., if the total score from the previous session was 9/16 trials correct or 9 points, the goal criterion for the current session was 10/16 trials correct, or 10 points). Following incorrect responses, the researcher gave contingent feedback (e.g., "No, that's not right. "[A] is not before [B], [A] is after [B]") and re-presented the trial.

Each training session continued until the participant responded correctly on each of the unique trial types. Participants progressed to testing of ME and CE relations across all stimulus once training criterion was met (14/16 trials correct across 2 sessions). If no upward trend was demonstrated across five data paths, participants were then exposed to training with only "before" trials (see trial types 1-8 in Table 2). Once criterion was met with "before" cues (7/8 trials correct across 2 sessions), participants were then exposed to training with only "after" cues (see trial types 9-16 in Table 2). Once criterion was met with "after" cues (7/8 trials correct across 2 sessions), participants were then re-exposed to the original trial block consisting of all 16 trial types across both contextual cues.

Generalization Probes

Once mastery criterion was reached with the targeted repertoire, participants were exposed to testing across all stimuli sets for both ME and CE trials. Generalization sessions were identical baseline sessions. No programmed consequences were administered for correct or incorrect responses. A participant was considered to pass a test for ME or CE if they responded correctly on 14/16 trials across 1 session. If a participant passed a test for one repertoire (e.g., ME) but failed the other (e.g., CE), they progressed to intervention with the failed repertoire. If the participant failed the repertoire that was just trained (e.g., ME), they were re-exposed to training at that same level with a new stimulus set (e.g., ME stimulus set 2). Once a participant passed generalization tests for both ME and CE, training ceased, and they progressed to a maintenance condition.

Maintenance

Approximately four weeks after training and generalization was completed, participants were tested again with both ME and CE trials. The maintenance session was identical to baseline and generalization sessions.

Interobserver Agreement and Procedural Fidelity

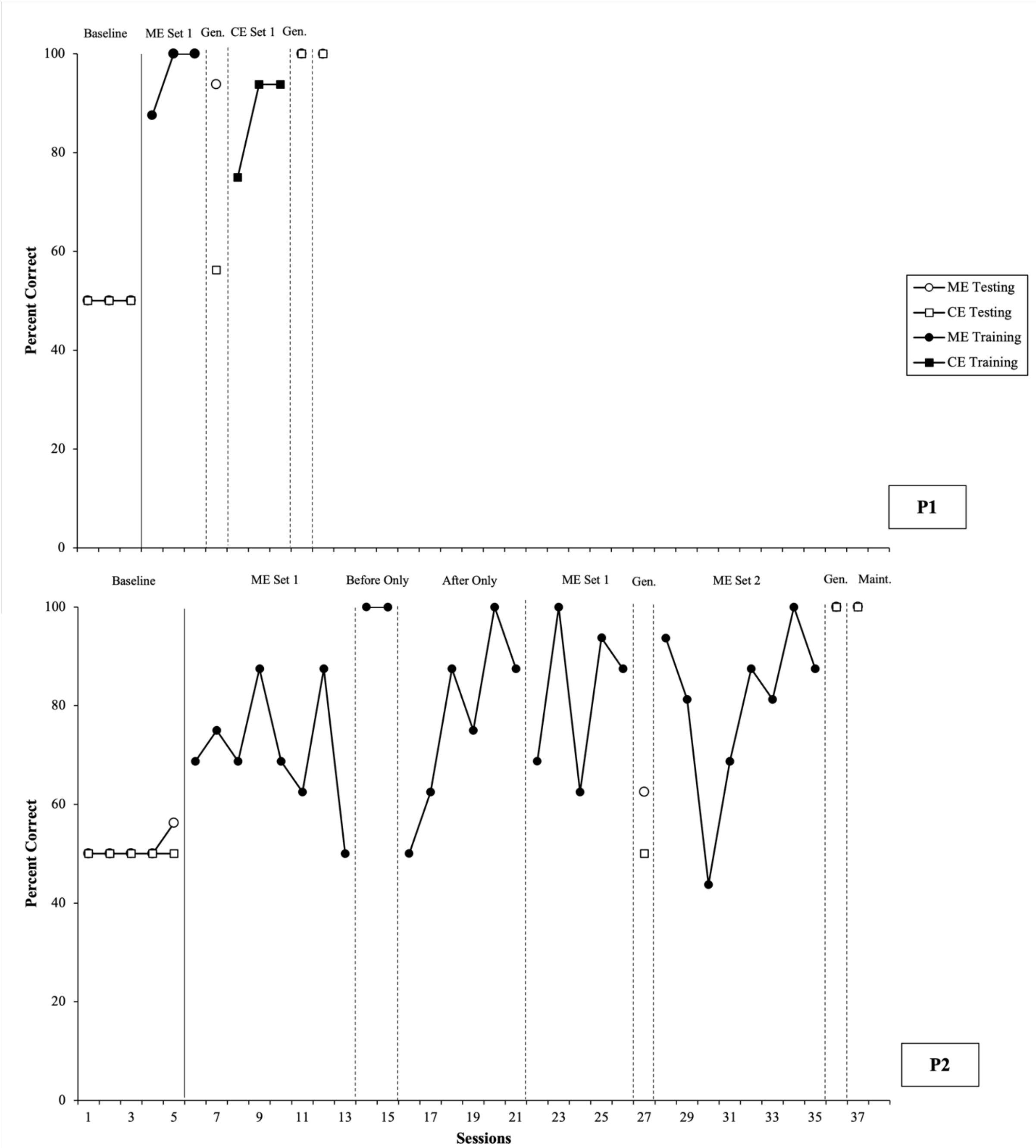
Interobserver agreement (IOA) and procedural fidelity data were collected by a trained research assistant. The research assistant attended 22% of the online sessions from a different physical location and their kept their audio and visual off during data collection. Both IOA and procedural fidelity data were collected on a trial-by-trial basis. IOA data was calculated by taking the total number of agreed upon trials divided number of total trials and was 99%. For procedural fidelity, trials were scored as correct or incorrect according to a fidelity checklist that included antecedent and consequence presentation for each condition. A procedural fidelity score was calculated by taking the total number of trials implemented correctly divided by the total number of trials and was 100%.

Results

Figure 4.1 shows percent correct on ME and CE trials for both participants during baseline, intervention, generalization, and maintenance conditions. During baseline, both participants scored near chance level responding for both repertoires. Following intervention, both participants reached criterion level responding and passed tests for generalization with ME and CE trials.

Figure 4.1

Percent Correct across Both Skills in Each Participant



Note. ME: mutual entailment; CE: combinatorial entailment.

Participant 1

P1 scored 50% correct for both ME and CE trials during each of the three baseline sessions. P1 entered training with ME and required 3 sessions to meet criterion. During the subsequent generalization test, P1 passed the test for ME (94% correct) and failed the test for CE (56% correct). Accordingly, P1 entered training with CE and required 3 sessions to meet criterion. During the following generalization test, P1 then passed tests for both ME and CE (100% correct each). In the maintenance session approximately four weeks later P1 again scored 100% correct with both ME and CE.

Participant 2

During baseline, P2's average percent correct for ME trials was 51% correct (range 50–56% correct) and 50% correct for CE (no range). Accordingly, P2 entered training with ME. As ME stimulus set 1 was introduced, no upward trend was observed and responding was variable (range 50-88% correct) across 8 sessions. As a result, P2 was then introduced to only "before" trials with the ME stimulus set 1 and required 2 sessions to meet criterion. P2 then was introduced to only "after" trials with ME stimulus set 1 and required 6 sessions to meet criterion. Following this, the standard ME trial set (including both "before" and "after" trials) was reintroduced. P2 required 5 sessions to meet criterion. During the subsequent generalization test, P2 failed tests for ME (63% correct) and CE (50% correct). P2 therefore was reintroduced to ME training but with stimulus set 2 and required 8 sessions to meet criterion. During the next generalization test, P2 passed tests for both ME and CE (100% correct each). P2 maintained performance with ME and CE (100% correct each) four weeks later during the maintenance session.

Performance across Contextual Cues

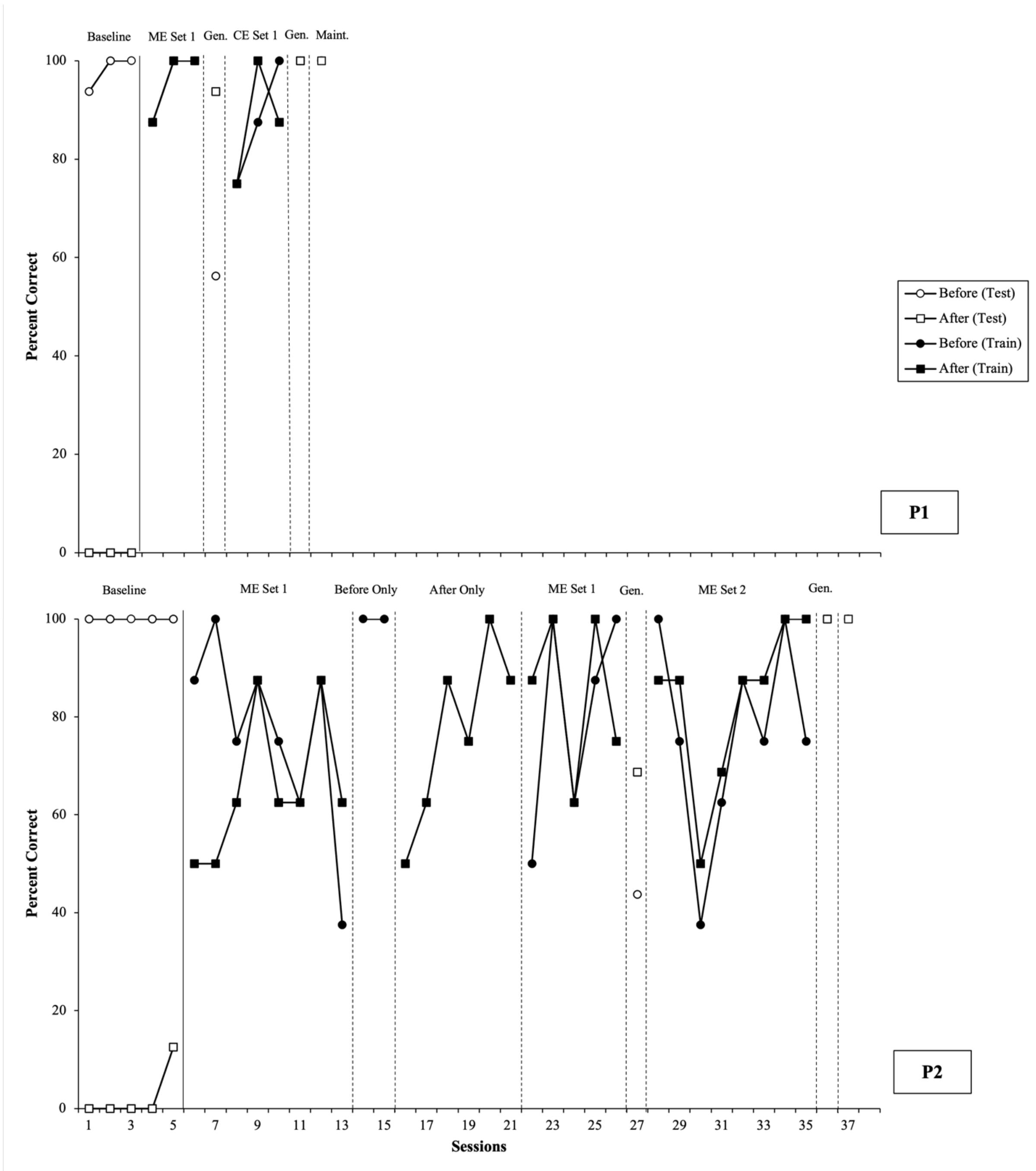
Figure 4.2 shows performance of both participants on trials with "before" as the stated contextual and trials with "after" as the stated contextual cue. The series labeled with "test" include the combined percent correct across both ME and CE with each contextual cue. The series labeled with "train" includes only the targeted repertoire during intervention.

P1's average percent correct on "before" trials during baseline was 98% correct and was 0% correct on "after" trials. During ME training, performance with both cues was identical across each of the three intervention sessions. During the first generalization test, P1 responded correctly on 56% of "before" trials and correctly on 94% of "after" trials. Across the three CE training sessions, P1 scored 75%, 88%, and 100% correct on "before" trials and 75%, 100% and 88% correct on "after" trials. During the second generalization test, P1 scored 100% correct with both contextual cues and this performance maintained post-training.

P2's average percent correct on "before" trials during baseline was 100% correct and was 3% correct on "after" trials. During initial ME training, P2's performance on "before" trials deteriorated across sessions while performance on "after" trials remained variable with no trend. When training was adjusted to include only "before" ME trials, performance returned to baseline levels (100% correct). As training progressed to "after" ME trials only, performance gradually improved from chance level responding to mastery criterion across 6 sessions. As interspersal of both contextual cues was reintroduced, variability in performance was observed across the 5 sessions with both "before" (range 50% to 100% correct) and "after" (range 63% to 100% correct) cues. During the first generalization test, P2 responded correctly on 44% of "before" trials and 69% of "after" trials. As ME training was re-introduced (stimulus set 2), variability in performance was again observed (range 38%-100% correct with "before" and 50%-100% correct with "after"). However, across these sessions, the data series patterns for each trial type more closely mirrored each other across sessions in contrast ME set 1. During the second generalization test, 2 scored 100% correct with both contextual cues and this performance maintained post-training.

Figure 4.2

Percent Correct on "Before" Trials and "After" Trials in Each Participant across All Phases



Discussion

This research aimed to pilot a testing and training procedure for mutually and combinatorially entailed temporal relations in two, 6-year-old typically developing children. Results showed that following implementation of MET, both participants met training criterion, passed tests for generalization, and maintained performance four weeks post-training.

While baseline performance was similar for both participants, performance during intervention revealed variation in the amount and type of trials needed to meet criterion and pass generalization tests. P1 required only 6 intervention sessions to pass generalization tests for both ME and CE. P2 however, required substantially more learning opportunities (29 intervention sessions) to pass generalization tests for ME and CE. Additionally, P2 required additional training sessions in which the contextual cues were isolated, as well as an additional stimulus set. Although P1 required minimal sessions, she required direct intervention for both ME and CE to pass generalization tests for each repertoire (i.e., training in ME alone did not result in passing a test for CE). P2, in contrast, require more sessions but only needed training on ME to subsequently pass a generalization test for CE.

Results also showed differences in responding on "before" and "after" trials during baseline that this was changed with intervention (Figure 4.2). Baseline responding for both participants was similar to the pattern observed in 6-year-olds by Neufeld et al. (2023). That is, accuracy on "before" trials was at a mastery level for both ME and CE while accuracy on "after" trials was near 0% correct for both ME and CE. The current study extends this work by introducing a training component that revealed that this response pattern was changeable via MET. By the end of testing and training, accuracy with both contextual cues reached 100% correct and maintained post-training. Consistent with other findings, the current data suggest that relational responding in accordance with arbitrary cues can come under antecedent and consequential control.

Another interesting finding in terms of contextual control with "before" and "after" cues is that promoting relational flexibility may be a relevant response dimension to examine more closely in terms of training designs. Relational flexibility refers to the extent to which a given instance of AARR can be modified by the current context (Barnes-Holmes et al., 2020). The more readily a person derives relations during shifting relational contexts, the more flexible the relational response. In the current study, this consideration was seen more evidently in the case of training for P2. Baseline levels were high accuracy with "before" cues and low with "after" cues. Upon introducing MET for ME with both cues, her accuracy with "before" cues specifically deteriorated across sessions. Due to this trend, "before" cues were then isolated, and P2's accuracy interestingly returned to baseline level immediately. When both cues were interspersed during training, two rounds of MET were required to meet criterion. It could be argued that trial blocks involving multiple contextual cues require more relational flexibility than having to respond to a single cue within the trial block, and thus may be more difficult to acquire. It is unclear if training with only one cue and subsequently mixing cues (see e.g., Berens & Hayes, 2007) would have been any more efficient or not. Future work could more systematically compare training designs in terms of how and when to program for flexibility to optimize skill acquisition with temporal AARR.

Certain limitations of the current study should be noted. Foremost, the current study utilized a nonconcurrent baseline design. Although nonconcurrent designs contain the baseline logic properties of prediction and replication, the verification of intervention effects is excluded (Cooper et al., 2020). The design is unable to control for history effects that may coincide with introduction of the independent variable and thus are arguably weaker than concurrent designs (Ledford & Gast., 2018). Additionally, the current investigated responses with only 2 participants. Future work should utilize a concurrent multiple baseline design with a higher number of participants to increase validity.

Other considerations for future work include specifics relative to the relational training protocol. The present study did not include any testing or training in terms of a transformation of function (ToF) consistent with the derived temporal relations. ToF is present in any derivation of a mutually or combinatorially entailed relation. However, ToF as a concept is distinguished from derived relational responding for practical reasons since a host of different functions can be transformed beyond simply derivation of relations (Belisle, Stanley, et al., 2020; Finn & De Houwer, 2021; Perez et al., 2015). The current study tested for contextually controlled mutually and combinatorially entailed relations (i.e., a ToF in the *relational* context). Future work should include a component to test for a stimulus function transformation with nonarbitrary properties of the environment within a particular *functional* context (i.e., whether behavior would be sequenced in accordance with the given relation).

Additional considerations relative to the training design are also suggested. Sessions in the present study involved 16 trials for ME and 16 for CE. Given the repetitive nature of the task itself, prolonged exposure to this many trials—particularly if many sessions are required—may lead to fatigue for learners at younger ages. It is worth considering whether similar outcomes could still be obtained using a lower number of trials, or in more naturalistic contexts. Second, the current study employed images of commonly known stimuli. Learners may have differing learning histories with each stimulus used and thus may have impacted acquisition. Future work could consider using different stimuli for the relational statements. Lastly, the present work incorporated both audio and visual presentation of the relational networks. That is, they were stated aloud and were shown on-screen. It is unclear whether using this combination of sense modalities facilitated or hindered acquisition.

In summary, the current study revealed an intervention design that can potentially be used for improving performance with arbitrary "before" and "after" relations at different levels of complexity in young children. Future work should replicate applications of this protocol as well as address the present limitations. Continued research is needed in this area and the current data offer encouraging first steps.

Chapter 5.
Training Temporal Relational Framing in Young Children

This chapter has been accepted for publication:

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Responding to the ways in which events are related in time is important to understanding event sequences and organizing one's behavior. Terms such as "before" and "after" are often used to indicate the temporal order of events, and hence accurately responding to event order requires responding appropriately in the presence of such terms.

A range of cognitive developmental and linguistic studies have explored "before" and "after" comprehension in young children (Blything et al., 2015; Clark, 1971; Keller-Cohen, 1987; McCormack & Hanley, 2011). These studies have typically involved presenting sentence variations describing an event sequence such as, "She brushed her teeth before she read the book"; "After she brushed her teeth, she read the book"; "Before she read the book, she brushed her teeth"; or "She read the book after she brushed her teeth." In one version of a "before/after" comprehension task, children observe a sequence of events (e.g., an animated character brushes her teeth and then reads a book). They then answer questions about the event order, such as by pointing to which event came first or last, or by pointing to the pair of images that matches the order described in the sentence. In a variation, children are instead tasked with acting out the events in the order specified in the sentence (e.g., "Take a blue circle after you take a red circle"; Trosborg, 1982). The data show that performance improves with age and that young children tend to perform better on sentences that state the events in the same order as how they were observed compared to sentences that state the events in the reverse order (Blything et al., 2015; Clark, 1971; Keller-Cohen, 1987; McCormack & Hanley, 2011). A limitation is that these studies mostly emphasized developmental differences and minimal research has investigated arranging conditions to improve performance when a child does not respond coherent with the terms.

One exception is that Amidon and Carey (1972) showed that 5-year-olds' performance on an act-out version of the task can be improved. They found that providing corrective feedback following errors (e.g., "No, that's not right" and model the correct response) improved performance. Additionally, they observed that providing vocal prompts in which the temporal term is stated more loudly did not improve performance. However, the training procedure used was relatively limited in scope and methodological description.

Behavior analytic research investigating the acquisition and training of "before" and "after" comprehension is also scarce. One approach that offers utility in this regard is relational frame theory (RFT; Hayes, Barnes-Holmes, et al., 2001). RFT is a contextual behavioral account of language and cognition that suggests that derived relational responding (DRR) is a key operant at the core of complex human behavior. Humans learn to derive relations between stimuli in various relational patterns (frames), including similarity, distinction, comparison, hierarchy, temporality, etc. Research with children has found that DRR is relevant to important language and cognitive-oriented skills, such as analogy (Carpentier et al., 2002), categorization (Mulhern et al., 2017), and perspective taking (McHugh et al., 2004).

From an RFT perspective, temporal frames are particularly relevant to following instructions involving temporal terms and ordering events in time (Neufeld & Stewart, 2023). Temporal relational framing involves responding to one event as being temporally related to another event. Like all frames, temporal frames are brought under the control of antecedent stimuli (contextual cues) that indicate the relational pattern. In this case, terms like "before" or "after" specify a frame of temporality. Temporal (and other) frames have three key properties. Mutual entailment is demonstrated when taught a relation such as, "A is after B," and then the reverse relation, "B is before A," is derived without further training. Combinatorial entailment is demonstrated when multiple entailed relations are combined such as, "A is after B, and B is after C," and then additional untaught relations are derived such as, "A is after C, or C is before A."

The third property, transformation of stimulus function (ToF), occurs when a function of a stimulus in a relational network is changed or transformed via derivation of relations through that network. Consider an instruction similar to certain "before/after" comprehension tasks (Trosborg, 1982): "Take a blue circle after you take a red circle." A child given this instruction may now take the colored circles in a particular order (i.e., red followed by blue). In other words, the stimuli have acquired sequential functions based on the derived relational network presented. From an RFT perspective, following this instruction involves both equivalence relations (between the words and events or objects) and temporal relations (cues specifying the order). If a child derives all the necessary relations specified in the instruction, they can "understand" the instruction. This may serve as a potential source of influence over behavior even without a direct learning history of the events or sequences described in the instruction.

Indeed, this RFT conception of instructional or rule-based control has been modeled empirically. O'Hora et al. (2004) trained and tested university students using a computer-based relational responding protocol. Arbitrary symbols were first trained as cues for "before/after" and "same/different" relations. After the cues were established, participants were tested for instructional control. This involved the presentation of relational networks including the arbitrary cues, and participants had to press computer keys in the correct sequence specified by the relational network. Across two experiments, 8 of 12 participants demonstrated sequenced responding in accordance with the relational networks involving "before/after" and "same/different" cues. Results provided evidence that sequences of responses can come under relational contextual control.

Later studies expanded this work by examining accuracy and response speed on nonarbitrary ordering tasks involving "before" and "after" (Brassil et al., 2019; Hyland et al., 2012; McGreal et al., 2016) For instance, McGreal et al. (2016) and Brassil et al. (2019) used a go/no-go task in which adults observed a sequence of stimuli on a computer screen one at a time (e.g., A…B). A statement about the sequence with either "before" or "after" then appeared on-screen and participants responded to whether the statement accurately described the sequence (e.g., B AFTER A; press key to affirm statement; B BEFORE A; no response to reject statement). A consistent finding across studies was that participants tended to respond faster on "before" cue trials than on "after" cue trials.

At present, research involving temporal relations has predominantly been restricted to experimental studies with adults with already well-established temporal framing repertoires and no work has yet been done to train derived "before/after" relations in children. However, RFT considers DRR an overarching, generalized operant (Hughes & Barnes-Holmes, 2016) and accordingly reasons that frames can be established and strengthened via multiple exemplar training (MET). MET involves interchanging a variety of stimuli as the relata, while the contextual cues remain the same. Differential reinforcement is provided for responding and children learn to relationally respond in accordance with the cues. Several studies have demonstrated that MET is an effective method for improving DRR in children across various frames (Barnes-Holmes, Barnes-Holmes, Smeets, et al., 2004; Berens & Hayes, 2007; Dunne et al., 2014; Kirsten et al., 2022b; Mulhern et al., 2018; Weil et al., 2011).

One format through which MET can be realized is the relational evaluation procedure (REP; see Cassidy et al., 2011; Stewart et al., 2004). This procedure requires participants to evaluate arbitrarily applicable relations given particular contextual cues (Whelan & Schlund, 2013). For example, a "relational statement" such as, "TIB is bigger than LEP" might be presented on-screen and participants could be tasked with either confirming or denying related relations (e.g., "Is LEP smaller than TIB?") by pressing either "yes" or "no." Across trials, relational statements could be rotated along with the targeted cues. This type of format is advantageous as it allows for a range of exemplars to be efficiently presented without extended baseline training (Kirsten et al., 2022b).

Studies have shown that this is an effective method to strengthen relational responding in children, and that such training can improve performance on standardized measures of cognitive abilities (Cassidy et al., 2011, 2016; Colbert et al., 2018; Hayes & Stewart, 2016). Many such studies thus far have used words as stimuli, which limits the benefits to children who are literate. Recent work has however successfully adapted this type of procedure for use with children who have yet to acquire a reading repertoire (Kirsten & Stewart, 2022; Kirsten et al., 2022a, 2022b). In this approach, colored shapes were used as stimuli instead of nonsense words, and single letters were used for contextual cues. For example, a relational statement of [red circle] S [blue circle] is displayed, which can be interpreted as, "red is the same as blue" and questions about the relational network can be asked.

The aim of the present study was to expand research on relational framing in children by training temporal frames with "before" and "after" cues in 5-year-old children using MET. A protocol similar to Kirsten et al. (2022a, 2022b) was used to train arbitrary mutually and combinatorially entailed relations. Additionally, an adapted version of the O'Hora et al. (2004) protocol was used to examine ToF in accordance with temporal relations.

Method

Participants and Setting

Three children participated. P1 was a female aged 5 years 5 months, P2 was a male aged 5 years 2 months, and P3 was a male aged 5 years 2 months. Participants were selected based on prior findings in which (i) this age group failed tests for arbitrary temporal relations (Neufeld et al., 2023) and (ii) children aged 5 years may have difficulty with "before" and "after" but their performance can be improved with training (Amidon & Carey, 1972). All participants were typically developing and attended schools in the west of Ireland. Ethical approval was first obtained from the research ethics committee at the host institution of the lead researcher. Parental consent and individual assent were obtained for each child.

All sessions were held online through Zoom at convenient times for the families via a networked device in their household. The primary researcher administered all sessions. Prior to each session, an accompanying family member assisted with ensuring all audiovisual features functioned properly. At the session onset, the family member did not remain on-screen but remained in a nearby room in their home. Sessions were held up to 3 times weekly, with each session lasting between 15-20 mins.

Experimental Design

A combination multiple probe design across participants and responses was used for this study. A multiple probe design was selected to reduce threats to internal validity and so that participants were not exposed to undesirably prolonged baseline conditions. Due to the number of trials and difficulty of the tasks, repeated testing could lead to undesirable behavior (Gilroy et al., 2015; Ledford & Gast., 2018). Participants were first exposed to baseline conditions in which all repertoires were tested: mutual entailment (ME), transformation of function via mutual entailment (ToF-ME), combinatorial entailment (CE), and transformation of function via combinatorial entailment (ToF-CE). Once stable responding across three sessions was observed, one participant (i.e., P1) entered intervention with one repertoire (i.e., ME) while the other repertoires remained untrained, and the two other participants remained in baseline. For P2 to enter training, P1 had to meet the training criterion with the targeted repertoire and for P3 to enter training, P2 had to meet the training criterion. For each participant, once training criterion was met with one repertoire, then another repertoire was targeted for training (e.g., ToF-ME) while the remaining repertoires remained in baseline (e.g., CE, ToF-CE).

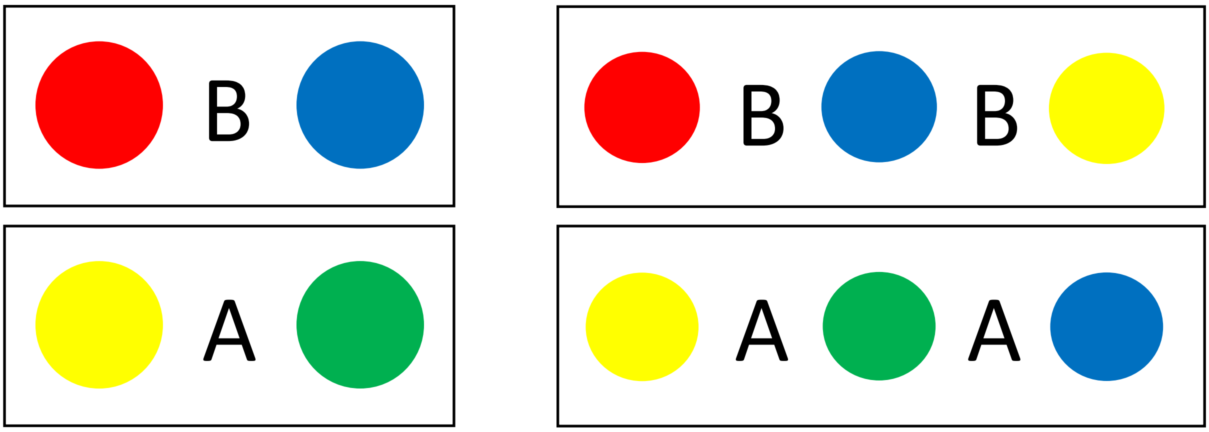
Materials

Session materials were displayed from a 13-inch MacBook Pro running Microsoft PowerPoint via the screen share feature of Zoom. Individual stimuli included images of colored circles, and the letters "B" or "A" representing the contextual cues, "before" and "after," respectively (Figure 5.1). For ME and ToF-ME trials, two colored circles with a contextual cue between them were used as the relational statements. For CE and ToF-CE trials, three colored circles with contextual cues between them were used as the relational statements. One set of four different colors was used for baseline and generalization sessions (red, blue, yellow, green) and a separate set of four different colors was used for training sessions (purple, black, orange, white).

Images of simple motor actions were also included for ToF trials. For all ToF-ME and ToF-CE trials, the left side of the screen showed each color-action combination, and the relational statement was presented on the right of the screen (Figure 5.2). One set of four actions was used for baseline and generalization sessions (clap, raise arm, touch nose, wave) and a different set of four actions was used for training sessions (thumbs up, cross arms, open mouth, touch head).

Figure 5.1

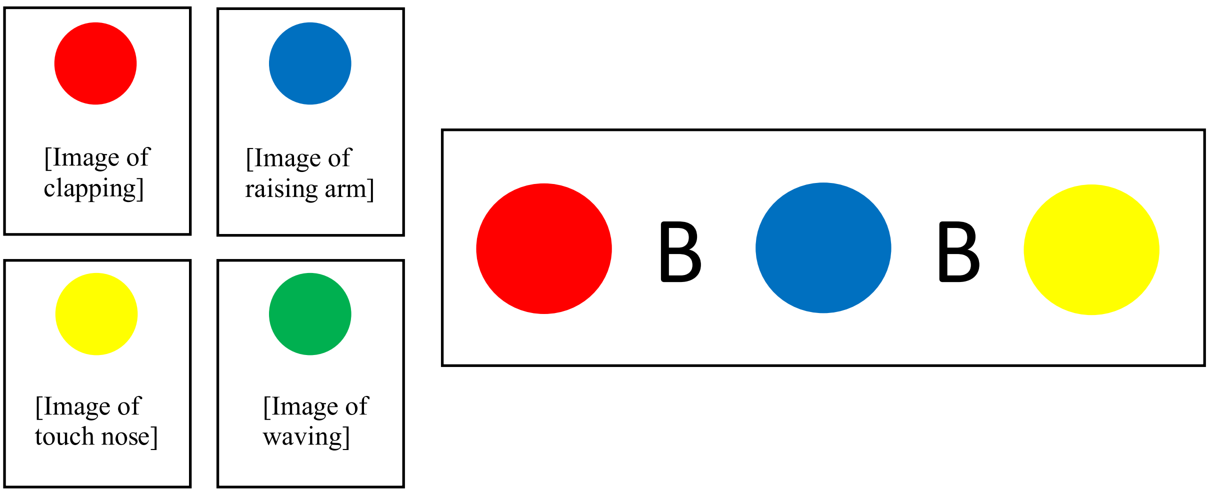
Example Relational Statements



Note. The left side of the figure show a mutual entailment trial with a "before" contextual cue (top left) and "after" contextual cue (bottom left). The right side of the figure shows a combinatorial entailment trial with a "before" contextual cue (top right) and "after" contextual cue (bottom right).

Figure 5.2

Example Stimuli Arrangement for Transformation of Function Trials



Note. The figure shows a sample stimulus arrangement on a transformation of function-combinatorial entailment trial (ToF-CE) with "before" contextual cues.

Measurement

Accuracy of responding was measured on trial probes across each repertoire (Table 5.1). For both ME and CE, a response was scored as correct if the participant gave a “yes” vocal response when the answer was yes, or a “no” vocal response when the answer was no. Scores were totaled out of 8 and converted to a percentage. For ToF-ME and ToF-CE trials, a response was scored as correct if the participant demonstrated the motor actions in sequence consistent with the order specified by the relational statement. For both ToF-ME and ToF-CE, there were four trials with “before” as the cue and four trials with “after.” Scores were totaled out of 8 and converted to a percentage.

Table 5.1

Trial types for Each Relational Response

Relational Level	Relational Statement	Question/Instruction	Correct Response
Mutual Entailment	A before B	Is A before B?	Yes
		Is B before A?	No
		Is A after B?	No
		Is B after A?	Yes
	A is after B	Is A before B?	No
		Is B before A?	Yes
		Is A after B?	Yes
		Is B after A?	No
Transformation of Function (ME)	A before B	Do these in order.	Action A then B
	A after B	Do these in order.	Action B then A
Combinatorial Entailment	A before B before C	Is A before C?	Yes
		Is C before A?	No
		Is A after C?	No
		Is C after A?	Yes
	A after B after C	Is A before C?	No
		Is C before A?	Yes
		Is A after C?	Yes
		Is C after A?	No
Transformation of Function (CE)	A before B before C	Do these in order.	Action A then B then C
	A after B after C	Do these in order.	Action C then B then A

Procedure

Screening and Pre-Training

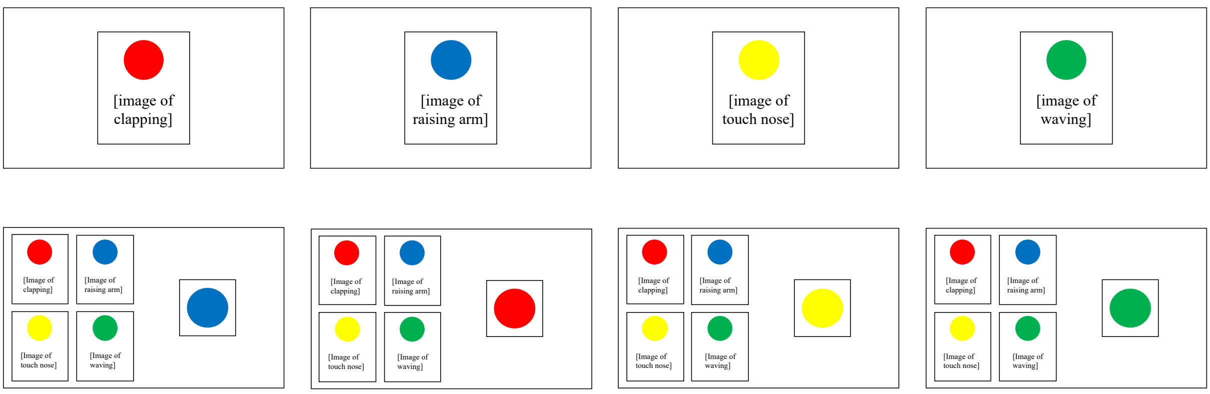
Participants were first screened on their ability to a) tact all stimuli used in the study, b) answer yes/no questions about the stimuli, c) perform one-step and multi-step motor actions that were included on ToF trials, and d) answer questions about nonarbitrary temporal relations (“Was A before/after? B" when shown images in sequence). Participants were required to score at least 90% correct on the tacting, yes/no, and motor actions tasks, and at least 75% correct on the nonarbitrary relations task. All participants passed the screening.

Following screening and prior to baseline, participants were introduced to the contextual cues, "B" and "A." The researcher displayed the letter "B" on-screen, stated that "B means before" and then asked the participant, "What does 'B' mean?" The same procedure was repeated with the contextual cue, "A." Participants were then shown a sample relational statement with each of the cues, such as [blue circle] A [green circle]. The researcher "read" the relational statement out loud and then asked the participant to read the same statement aloud.

Next, the researcher trained a discriminative function (for a particular motor action) with each of the colored circles used on the ToF trials. Participants were first shown one of the four colored circles on the screen, along with an image of a particular action (top row of Figure 5.3). The researcher stated, "This [color] means [action]" while also demonstrating a model of the action. This was repeated with the three remaining colors. Participants were then taught to demonstrate the corresponding action when shown the color (alongside a visual depicting each color-action combination, bottom row of Figure 5.3). For instance, the researcher presented the color green, and issued the instruction, "Do this one." Social praise was delivered for a correct response and corrective feedback was given for an incorrect response. Each participant was required to respond with the correct motor action with each of the four colors before proceeding. All participants responded accurately with each color-action combination during initial training.

Figure 5.3

Example Flow of Presented Stimuli During Color-Action Pre-Training



Note: Each box represents a separate display on-screen. The order of presentation reads left-to-right on the top row and then left-to-right on the bottom row.

Baseline

For all baseline sessions, participants were exposed to each of the 8 ME trials, then 8 ToF-ME trials, followed by 8 CE trials, and then 8 ToF-CE trials, for a total of 32 trials per session. During each baseline session, one of the relational statements was presented on-screen at the onset of a trial and then the researcher read aloud the presented relational statement (e.g., "Red is before blue"). The participant was then asked a question about the relation (e.g., "Is blue after red?") during ME and CE trials. During ToF trials, participants were instructed to perform the actions in the order specified by the relational statement (i.e., "Do these in order"). Once the participant responded, the screen was changed to the next trial and the procedure repeated. During baseline, no feedback was provided for correct or incorrect responses. A session ended once each of the trials was presented.

Intervention

Following baseline, participants were exposed to training in phases: ME then ToF-ME, then CE, then ToF-CE. For all training sessions, trial presentation was identical to baseline, with the exception of programmed consequences for responses. Prior to training, the researcher obtained a list of preferred interests for each participant via caregiver report to establish potentially reinforcing activities. At the onset of training sessions, the researcher asked the participant what kind of activity they would like to do following the teaching activities (e.g., a video or a game). If the participant did not state a preference, the researcher provided a sample of options based on their interests. During training, correct responses were reinforced on a continuous schedule of reinforcement with specific verbal praise (e.g., "Nicely done! [A] is after [B]!") and token delivery. Tokens (points) were given to a virtual avatar selected by the participant in ClassDojo, which was visible to the participant via screen share. Tokens could then be exchanged for access to the selected preferred activity once the session goal criterion was met (Berens & Hayes, 2007; Mulhern et al., 2018). For each session, a goal criterion was designated based on performance from the previous session (e.g., if the previous session score was 6/8 trials correct or 6 points, the goal criterion for the current session was 7/8 trials correct or 7 points). Following incorrect responses, the researcher gave contingent feedback (e.g., "No, that's not right. "[A] is not before [B], [A] is after [B]") and re-presented the trial.

Each training session continued until the participant responded correctly on each of the unique trial types for the targeted relational response. Participants progressed to generalization testing across all repertoires once training criterion was met (100% correct for 1 session or 85% correct across 2 consecutive sessions). It was also determined that if no upward trend was demonstrated across five data paths (Greer & Ross, 2008), participants would then be exposed to training with only "before" cues. Once criterion was met with "before" cues, participants would then be trained with only "after" cues. Once criterion was met with "after" cues, participants would then be re-exposed to the original trial block consisting of trials with both cues. No participant required this additional training phase.

Generalization

In between each training phase, participants were tested across ME, ToF-ME, CE, and ToF-CE. Generalization probes were identical to baseline in which no programmed consequences were administered. The same untrained stimulus set used in baseline was also used for generalization probes.

A participant was considered to pass a generalization probe if they scored above 85% correct for that repertoire. Depending on performance during generalization probes, participants continued in one of three possible ways: progress to the next training phase, skip ahead to a latter training phase, or repeat the previous training phase. For example, if the trained skill was ME and the participant passed the generalization test for ME but failed testing with the next untrained skill (i.e., ToF-ME), they proceeded to training at that level. Alternatively, if the participant passed a test for the trained skill of ME and also passed the generalization test for the untrained skill of ToF-ME, they skipped ahead and entered training at the next level that was failed (e.g., CE). Lastly, if a participant was trained in ME but then failed the generalization test for ME, they were then re-exposed to training at the same level.

Maintenance

Following completion of all training and generalization testing, each participant was subsequently tested again approximately four weeks later on ME, ToF-ME, CE, and ToF-CE. The maintenance session was identical to baseline and generalization sessions.

Procedural Fidelity and Interobserver Agreement

Procedural fidelity and interobserver agreement (IOA) data were collected by a trained research assistant for each participant across each condition. The research assistant attended the sessions from a different physical location and kept their audio and video off during observations. Procedural fidelity and IOA data were collected in 30% of sessions. Procedural fidelity was assessed on a trial-by-trial basis alongside a fidelity checklist, in which a trial was scored as correct or incorrect. For a trial to be scored as correct, all criteria had to be adhered to according to the condition and trial type, including trial presentation and consequences administered. Procedural fidelity was found to be 99%. IOA data was calculated on a trial-by-trial basis by taking the number of agreed upon trials divided by the number of total trials for a given session; IOA was 99%.

Results

Overview

Results for all participants are shown in Figure 5.4, which displays percentage of trials correct for each repertoire: ME, ToF-ME, CE, and ToF-CE for baseline, training, generalization, and maintenance conditions. An analysis of baseline data indicated no participant demonstrated the target relational repertoire across consecutive sessions. When MET was introduced, each participant met training criteria for the targeted relational response(s) and passed tests for generalization. As this study involved multiple components, we will first discuss results for each participant for clarity.

Participant 1

In baseline, P1's average percent correct for ME was 56% correct (range 38–88% correct); ToF-ME was 47% correct (range 38–50% correct), and both CE and ToF-CE were 50% correct in each session. During the first baseline session, P1 showed a high level of accuracy on ME trials (88% correct), however this stabilized to near chance levels during the subsequent three baseline sessions.

Accordingly, P1 entered training at the ME level. P1 required eight sessions to reach mastery criterion (100% correct), and subsequently passed the generalization test for ME (100% correct), as well as for the untrained ToF-ME (88% correct). During this generalization probe, P1 failed tests for CE (75% correct) and ToF-CE (37% correct). As a result, P1 then entered training for CE and required five sessions to meet criterion (two consecutive sessions at 88% correct). P1 subsequently passed a generalization test for ME, ToF-ME, and CE (each 88% correct) but failed the test for the untrained skill of ToF-CE (50% correct). Following four training sessions for ToF-CE, P1 met criterion (100% correct) and passed generalization testing for all responses. During the maintenance session, P1 maintained three of the four the relational responses (≥ 85% correct), with ToF-CE returning to baseline level (50% correct).

Participant 2

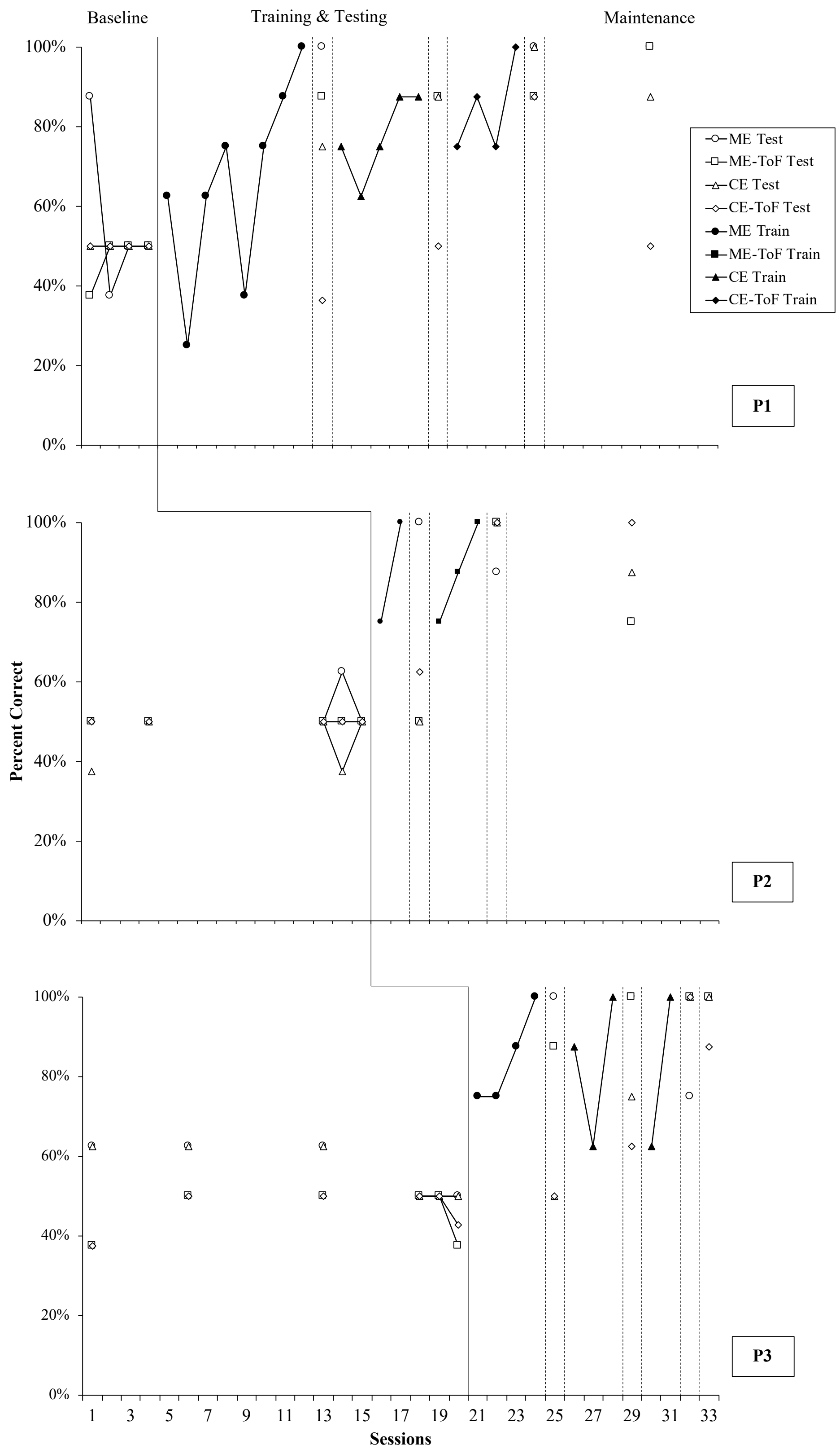
P2's average percent correct in baseline for ME was 53% correct (range 50–63% correct), ToF-ME was 50% correct (no range), CE was 45% correct (range 38–50% correct) and ToF-CE was 50% correct (no range). P2 entered training for ME and required two sessions to meet criterion (100% correct). P2 passed the generalization test for ME (100% correct), while the other untrained responses remained near baseline level. Training proceeded to ToF-ME, and P2 required three sessions to meet criterion (100% correct). P2 subsequently passed a generalization test for all responses, including the untrained responses for CE and ToF-CE. During the maintenance session, P2 scored 75% correct on ME and ToF-ME, 88% on CE, and 100% on ToF-CE.

Participant 3

For P3, his average percent correct in baseline for ME was 56% correct (range 50–63% correct), ToF-ME was 46% correct (range 38–50% correct), CE was 56% correct (range 50–63% correct), and ToF-CE was 47% correct (range 38–50% correct). P3 also began training at the ME level. P3 required four training sessions to meet criterion (100% correct) and passed the generalization test for ME (100% correct) as well as for the untrained ToF-ME (88% correct). During this test, P3 failed generalization probes for CE and ToF-CE (each 50% correct), so intervention progressed to training CE. P3 required three sessions to meet the training criterion (100% correct) but did not pass the generalization test for CE (75% correct) or ToF-CE (63% correct), while performance with ME and ToF-ME remained at 100% correct. Accordingly, P3 was then re-exposed to training at this level and required two additional training sessions to meet criterion with CE trials (100% correct). On the subsequent generalization test, P3 scored 75% correct on ME and 100% correct on each of the other relational responses, including the untrained ToF-CE. During the maintenance session, P3 maintained a high level of accuracy for all relational responses (100% correct on ME, ToF-ME, and CE, 88% correct on ToF-CE).

Figure 5.4

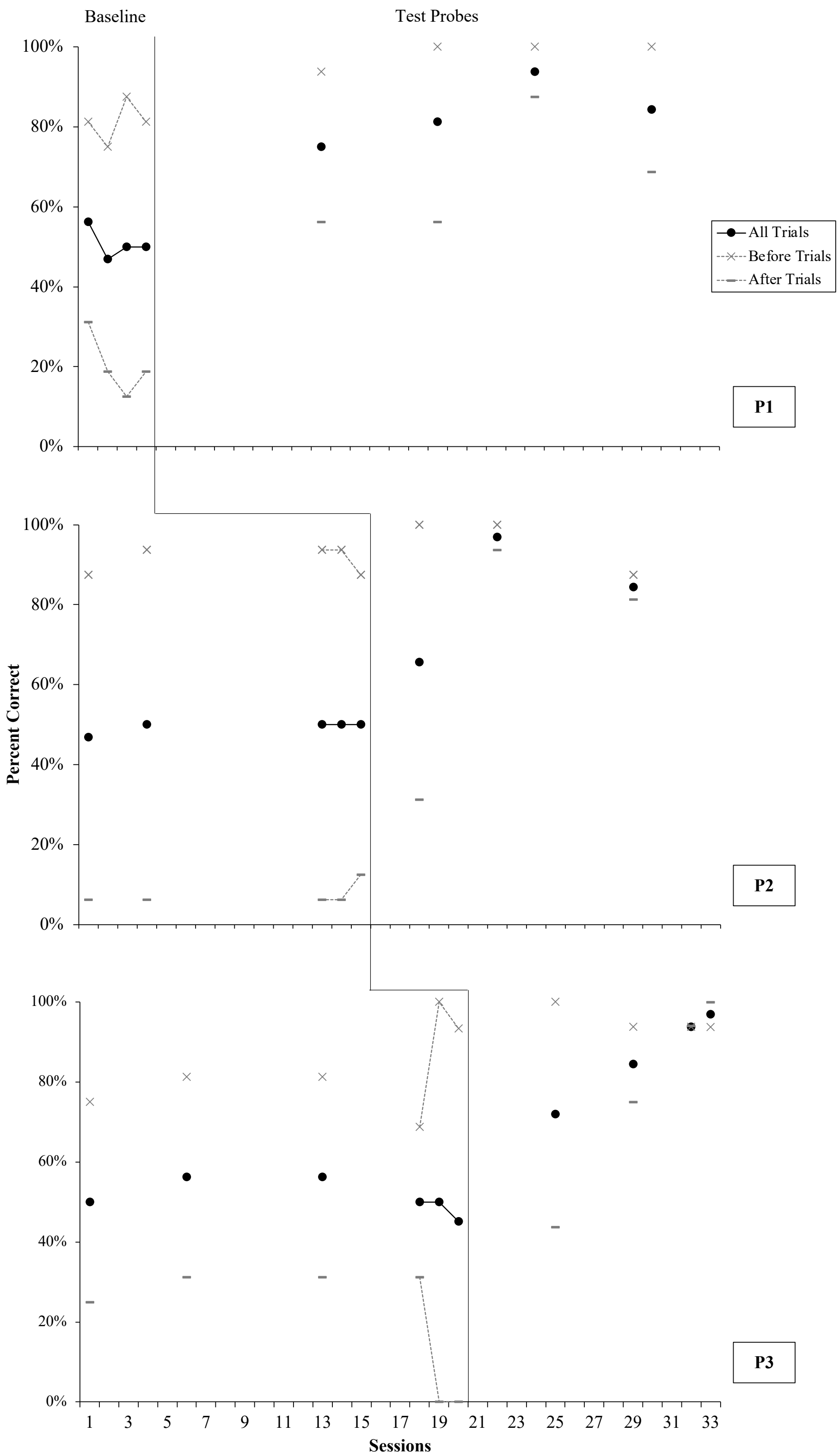
Combined Multiple Probe Design Across Participants and Responses



Note. ME: mutual entailment; ME-ToF: transformation of function of mutually entailed relations; CE: combinatorial entailment; CE-ToF: transformation of function of combinatorially entailed relations.

Figure 5.5

Participant Responses During Baseline and Testing Sessions



Note. All Trials: includes all responses with both contextual cues across all skills. Before Trials: includes only responses on "before" trials across all skills. After Trials: includes only responses on "after" trials across all skills.

Performance Across All Trials

Performance across all responses on baseline and testing sessions for each participant is shown in Figure 5.5. That is, the “all trials” data series depicts the overall percent correct across ME, ToF-ME, CE, and ToF-CE trial probes. Each participant’s overall performance in baseline remained near 50% correct responding (averages of 51% correct for P1 and P3, 49% correct for P2). As training in the relational responses was introduced, performance improved in each participant and as subsequent responses were trained, overall accuracy improved. Accuracy across all relational responses slightly decreased post-training in P1 and P2 but remained at a high level (84% correct for both participants) while P3’s accuracy across all trials was highest during post-training (97% correct).

Performance on “Before” and “After” Trials

Figure 5.5 also shows overall performance for each participant on trials with “before” as the contextual cue in the relational statement compared to trials with “after” as the contextual cue in the relational statement. During baseline for each participant, accurate responses on “before” trials were consistently and substantially higher than “after” trials. P1 averaged 81% and 21% correct on “before” and “after” trials, respectively; P2 averaged 92% and 7% correct on “before” and “after” trials, respectively; and P3 averaged 83% and 20% correct on “before trials” and “after” trials, respectively. As training was introduced and progressed for each participant, performance on “after” trials significantly improved. During the last generalization session for each participant, P1 scored 100% and 88% correct on “before” and “after” trials, respectively; P2 scored 100% and 94% correct on “before” and “after” trials, respectively; and P3 scored 94% correct on trials for both contextual cues. During the maintenance session, P1’s performance maintained at 100% correct for “before” trials and decreased to 69% correct on “after” trials. P2 scored 88% and 81% correct for “before” and “after” trials, respectively. P3 scored 94% correct on “before” trials and 100% correct on “after” trials.

Discussion

This study aimed to train temporal relational framing based on “before” and “after” cues across multiple levels of complexity in three, typically developing 5-year-olds. Results showed that following intervention, each participant met training and generalization mastery criteria for each relational response, and that overall accuracy maintained four weeks later. The present data also showed that each participant had greater difficulty with “after” trials compared to “before” trials at baseline. Following training, each participant demonstrated contextually controlled relational responding in accordance with both cues.

The present study adds to previous research showing that DRR is trainable through MET. Although this has been demonstrated with a variety of other relations (Barnes-Holmes, Barnes-Holmes, Smeets, et al., 2004; Berens & Hayes, 2007; Dunne et al., 2014; Mulhern et al., 2018; Weil et al., 2011), this is the first study to train temporal frames in children. Prior studies have shown that temporal relational responding can come under arbitrary contextual control, but such work has been limited to adult participants (Brassil et al., 2019; Hyland et al., 2012, 2014; McGreal et al., 2016; O'Hora et al., 2004, 2005, 2008). Further, the present study adds to the literature showing that the REP is a useful format that can be adapted for use with young children (Kirsten et al., 2022a, 2022b).

Results also highlighted different training needs across participants. P1 required direct training on ME and ToF-ME in order to pass generalization tests for these responses. Once ME and ToF-ME were trained, P1 subsequently passed a generalization test for CE without requiring training, but still required direct training for ToF-CE. For P2, once ME was trained, he still required directing training for ToF-ME. Once both ME and ToF-ME were trained, he then passed generalization tests for CE and ToF-CE without direct training. P3 was similar to P1 in that after ME training, he passed a generalization test for ToF-ME. P3 required direct training on both CE and ToF-CE in order to pass generalization tests. Nonetheless, in the case of all participants, MET was effective for training each relational response when needed.

There are at least two implications of this result. First, it suggests that testing each relational response is an important consideration in interventions targeting derived relations. One tool that offers utility in this regard is the hyperdimensional multilevel (HDML) framework, which distinguishes between increasingly complex levels of relational responding (see Barnes-Holmes et al., 2020). The current study examined two types of derivation that are posited as separate levels of the HDML, that is, ME (Level 1) and CE (Level 2). Thus, these types of derivation are sufficiently different from each other such that, for example, even if ME has been acquired, this might not be a robust indicator of the likelihood of soon thereafter acquiring CE. The current data provided some indication of this separation for two of the three participants for whom training in ME alone did not lead to demonstrations of CE. At the same time, it is important to note that within the HDML separate levels of relational behavior are not necessarily "stages" but rather, lower levels of relating may provide a relevant historical context for the higher-level patterns of relating (Barnes-Holmes et al., 2020, p. 609). In the case of P2 who did not require direct training in CE, it is possible that this response was already at least partially established in his repertoire and that training with arbitrary "before" and "after" cues during ME facilitated CE responding as well.

Second, it should not be assumed that if an individual is trained in particular patterns of DRR, that a certain transformation of function in terms of nonarbitrary stimulus properties will always occur. Belisle, Stanley, et al. (2020) suggested that in some RFT studies, ToF with nonarbitrary stimulus properties is assumed to occur but may not be warranted. As the authors noted, without this ToF effect in terms of the physical environment, there is no referential meaning of the established arbitrary relational networks. To that end, we sought to test for ToF throughout the study. Results showed that even when particular relational responses were established, participants on occasion still required direct training to show corresponding ToF. P2 required training on ToF-ME even after ME training, while P1 and P3 both required training on ToF-CE after CE training. However, in some circumstances, training in arbitrary relations was sufficient for ToF to also appear. Future research should further investigate demonstrations of ToF across patterns and levels of DRR, and incorporate other stimulus functions, particularly in young populations in whom such patterns of responding may still be emerging.

Another key finding was that clear differences in responding were observed between “before” and “after” cues prior to intervention, and that this was changeable via MET for all participants. Each participant showed high accuracy on “before” trials and low accuracy on “after” trials in baseline, which is consistent with prior findings (Neufeld et al., 2023). Accuracy on “after” trials significantly improved only when training was introduced. While the improvement in performance on “after” trials was more pronounced, improvements on “before” trials were also observed but to a smaller degree given the already high level of accuracy in baseline. An at least partially previously acquired repertoire of relationally responding in the presence of “before” cues might have accelerated the acquisition of the complete repertoire of “before/after” relations. This may have provided a foundation upon which the latter might be built, in contrast to a situation in which a participant had a low or non-existing repertoire of responding to both “before” and “after” cues. Future work could empirically examine this issue. Overall, this data indicates that DRR in accordance with arbitrary “before” and “after” cues can be facilitated through relational training procedures. This result is consistent with other RFT studies, which suggest DRR is an operant behavior that can be strengthened and come under arbitrary contextual control (Barnes-Holmes et al., 2004; Berens & Hayes, 2007; Healy et al., 2000; O’Connor et al., 2011).

The response patterns observed with “before” and “after” cues might also be analyzed through the HDML framework. Relational responses can be examined across multiple dimensions and particularly relevant here is the dimension of coherence: the extent to which a derived relational response is consistent with other patterns of relating. One possible reason for the greater accuracy on “before” trials is that there is higher coherence than on “after” trials. On “before” trials, there is coherence between the description of a sequence in the relational statement (e.g., “[red] B [blue]”) and the actual nonarbitrary appearance of stimuli in time (e.g., hearing or reading, “red” then “blue”). In hearing the statement, the nonarbitrary temporal relation is given. In reading the statement, the reader produces the temporal order based on the given spatial order in the statement (i.e., orienting to stimuli from left-to-right). Even if a child does not have a reading repertoire, they might still have a learning history in which a linear arrangement of stimuli will evoke orienting to the stimuli from left-to-right. Socioverbal communities represent time in a specific spatial order, such as writing direction (Fuhrman & Boroditsky, 2010), and this preference becomes increasingly pronounced between early childhood and adulthood (Tillman et al., 2022). Because “before” trials offer higher coherence than “after” trials, participants may be more likely to derive the correct answer in the former than in the latter.

The present study also contributes to the wider literature on temporal responding in children. Studies examining “before” and “after” comprehension in children have, from an RFT view, typically relied on nonarbitrary temporal relations when children are tasked with reporting on an observed sequence of events (e.g., Blything et al., 2015). Additionally, studies have mostly been descriptive in terms of age-level performance with little emphasis on antecedent and consequential variables. The current study addresses both limitations by providing a method to examine responding with "before" and "after" cues at a more symbolic level (DRR) and demonstrating that correct responding could be increased through operant training procedures.

There are limitations to the present study that future research should address. First, results indicated that not all targeted repertoires maintained post-training at a high level in each participant. For P1, her performance on ME, ToF-ME, and CE maintained at a high level of accuracy but her performance on ToF-CE returned to baseline level (50% correct). More specifically, her pattern of responding on ToF-CE during the maintenance probe was 100% correct with "before" trials and 0% correct with "after" trials. For P2 during the maintenance probe, he performed worse on the presumably simpler trials, ME and ToF-ME (75% correct on both), compared to CE (88% correct) and ToF-CE (100% correct). One possible explanation for this performance is that a practice effect may have occurred during the maintenance probe. Since trials were presented in the order of ME, ToF-ME, CE, then ToF-CE, P2 may have been becoming re-familiarized with the tasks that were previously learned. Future RFT research should examine to what degree patterns of DRR maintain over time consistent with intervention versus how those stimuli were related prior to intervention. Additionally, incorporating a testing condition in which the different levels of relational responses are interspersed (i.e., not presented in a particular order) could offer a more robust indication of skill mastery.

A second possible critique of this study is that a more stringent mastery criteria could have been used, such as by incorporating response fluency (Binder, 1996). This consideration may be relevant to the prior limitation regarding maintenance of performance. Training relational responses to a higher level of fluency may have in turn impacted skill maintenance. Including response rate or response latency as measures could also offer greater insight into comparing performance with "before" and "after" cues in children. For instance, existing RFT studies with nonarbitrary temporal relations tasks incorporated a response latency measure, which found that adults tended to respond slower on "after" trials (Brassil et al., 2019; Hyland et al., 2012; McGreal et al., 2016). This could be extended to children and with solely arbitrary relations in future work. It is recommended that future research on relational framing in children consider mastery factors such as fluency, flexibility, and retention of relational responses into their training designs.

Future studies might also consider other variations in terms of stimuli employed or responses examined. For instance, the letters "B" and "A" were used as "before" and "after" contextual cues in this study. This was consistent with the approach of Kirsten and Stewart (2022) in which initials were selected as cues as opposed to the full names (e.g., the text "before" and "after") to make it easier for young children to "read" the relational statements. One consideration in terms of the initials used in this study, is that children may have a pre-experimental history with typically sequencing “A” before “B” in the context of the alphabet. It might be argued that this could have made it more difficult to learn that “A” represents “after.” It seems relatively unlikely that this might have been the case, however, as a function involving the sequencing of potential cues is different from a function involving contextual control over the sequencing of other stimuli. While the sequencing of letters in the alphabet might affect the former, it was the latter that was relevant in the present study. This study also only presented relational statements in a left-to-right spatial direction to simplify the procedure for children and to be consistent with other applications of the REP (Cassidy et al., 2016; Kirsten et al., 2022b). However, certain considerations might be applicable in the case of temporal framing. As children have a gradually acquired learning history of sequencing stimuli in a particular spatial direction with temporal terms like “before/after,” arranging stimuli in this way may be a factor in terms of performance. Future research might consider alternative stimuli arrangements to examine any potential differences in responding. Lastly, future work could include measurement of additional responses such as orienting responses toward the stimuli (e.g., eye-tracking), nonlinear relations (e.g., “A before B, B after C”), and/or higher levels of relating described in the HDML framework.

In summary, the present study adds to the limited literature on temporal relational framing. Results from this preliminary work show that contextually controlled patterns of temporal relational framing can be trained in young children using MET. Given the prevalence and importance of time-related skill sets in everyday life, more work is needed to comprehensively explore the acquisition and training of temporal relational repertoires and how they support more complex skill sets.

Chapter 6.

Teaching Nonarbitrary Temporal Relational Responding in Adolescents with Autism

This chapter has been accepted for publication in The Analysis of Verbal Behavior.

Time, as an abstract verbal concept, is intricately woven with language (Hayes, 1992). Early in development, children learn to orient themselves in time and talk about events according to the temporal order in which those events occur (Fivush & Mandler, 1985; Friedman, 1990). As children age, there is a gradual shift towards also using symbolic systems like the clock and calendar to orient themselves in time (Tartas, 2001; Tillman & Barner, 2015; Tillman et al., 2017). The ability to verbally order events in time, and to understand temporal relations more generally, is understood from a relational frame theory (RFT) perspective as temporal relational responding. Temporal relational responding can be approached as a specific pattern of the overarching operant of relational responding: responding to one stimulus based on its relation to another stimulus.

RFT distinguishes between two forms of relational responding: nonarbitrary relational responding (NARR) and arbitrarily applicable relational responding (AARR) (Kenny, Barnes-Holmes, et al., 2014). NARR is a form of relational responding that is based on the physical or formal properties of the stimuli (Stewart, Barrett, et al., 2013). Thus, nonarbitrary temporal relations are primarily based on actual experiential change in the environment from one moment to the next. For example, consider a child that completed a puzzle and then ate a snack. When asked, "What did you do before snack time?" the correct response (puzzle) is indicated by how the events were sequentially experienced in time. In contrast, AARR is a more advanced variety of relational responding based primarily not on the formal or physical properties of related stimuli, but instead on features of the context that specify the relation (Hayes, Barnes-Holmes, et al., 2001). Hence, arbitrarily applicable temporal relations are based on contextual cues that can indicate a temporal pattern (e.g., "before," "after," "earlier," "later") without reliance on direct experience of sequential order. For instance, a child being told that historical event X happened before historical event Y might derive that Y happened after X, without seeing either event actually happen. This ability is key to understanding time at an abstract level, which allows relatively complex levels of planning and organization with respect to events (Neufeld & Stewart, 2023; Chapter 2).

Although NARR is primarily controlled by the physical relations between stimuli, contextual cues are often still involved. A child may first learn to respond to contextual cues applied to nonarbitrary relations. For example, a child may initially learn to respond to contextual cues like "before" and "after" with events they sequentially experience (e.g., brushing one's teeth before going to bed). Once generalized responding has been acquired, relational control with the contextual cues can then transfer to scenarios in which physical properties are no longer key; for example, learning that their new friend's birthday falls before their own. Some research has shown that learning a particular pattern of NARR may emerge earlier in development than its AARR counterpart (Kirsten & Stewart, 2022; Mulhern et al., 2017). Other work has highlighted that training with nonarbitrary relations may also help facilitate acquisition of AARR (Barnes-Holmes, Barnes-Holmes, Smeets, et al., 2004; Berens & Hayes, 2007). These findings are coherent with RFT predictions (Hughes & Barnes-Holmes, 2016). NARR has a similar relational pattern to AARR, but it is concrete as opposed to abstract and thus simpler and more likely to come first, as well as to provide a useful foundation for AARR.

Most research on nonarbitrary temporal relations thus far has been conducted with neurotypical adults involving sequential responding (Brassil et al., 2019; Hyland et al., 2012; McGreal et al., 2016). As one example, Hyland and colleagues (2012) investigated accuracy and response speed with temporal relations in 20 adult university students. In their two-part study, the relative effects of temporal relational cues, "before" and "after," on temporal order judgements were evaluated. In Study 1, participants were exposed to familiar shapes and completed a temporal relations task to describe the sequence of the shapes. Participants first observed a sequence of two shapes that appeared on a screen one at a time (e.g., circle…square). Next, a "before" or "after" contextual cue appeared on the screen in between a set of shapes on both the left and right side of the screen. Participants had to select the shapes in the order consistent with the contextual cue. For example, if "after" was presented, a correct response was to select square on the left side of the screen and circle on the right side. Results indicated that participants responded significantly faster to "before" statements in comparison to "after" statements. Such findings were replicated in Study 2, in which abstract stimuli were utilized in comparison to familiar stimuli.

To date, two studies have examined temporal relational responding in children with "before" and "after" cues. Kirsten and Stewart (2022) assessed 24 between 3-7 years old on a relational responding test that included a variety of relations and levels of complexity. During the nonarbitrary temporal relations section, participants observed two sequentially presented shapes and answered questions about their order (e.g., "Which one was before/after?" or "Was stimulus 1 before or after stimulus 2?"). During the arbitrary temporal relations section, participants were presented with a relational statement that consisted of colored shapes with a "before" or "after" contextual cue between them (e.g., "[red] B [green]"). Participants were then asked questions that tested for directly trained, mutually entailed, or combinatorially entailed temporal relations. Results showed that across age cohorts, performance on nonarbitrary temporal and opposition relations was lower than that on other nonarbitrary relations (coordination, comparison, hierarchy). Similarly for the arbitrary relations section, derived temporal relations appeared to emerge later than other derived relations, and only the 6-7 years participants scored above chance.

Neufeld et al. (2023) tested 25 children between the ages of 3-8 years old in nonarbitrary and arbitrary temporal relations using a more comprehensive protocol than the one used in Kirsten and Stewart (2022). During the temporal NARR portion of the assessment, children were shown 2- and 3-image sequences of common stimuli on a screen one at a time and answered "before" and "after" questions about the image sequence (e.g., "Was apple after cat?"). A similar method to that employed in Kirsten and Stewart (2022) was used to assess arbitrary relations but involving a greater number of trials. A test for transformation of function was also included in which simple motor actions were assigned to each stimulus in the relational statement and participants had to sequence their actions in the order specified by the relational statement. For example, when taught that red = clap, blue = raise arms, and yellow = wave and provided a relational network of “red after yellow after blue,” participants were to sequence their actions by raising their arms, then waving, then clapping. Results showed that accurate responding on the NARR task appeared to emerge between 5-6 years of age and similar levels of accuracy were observed with both “before” and “after” questions across the age cohorts on the temporal NARR task. In contrast, participants performed notably better with “before” cues than “after” cues on the arbitrary trials and no age cohort fully met mastery criterion with both cues on the temporal AARR section. This points to a deficit in temporal understanding in young children that might help explain other deficits also found at these ages (e.g., such as in planning and organization), and that might be a target of teaching.

Although this work sheds some light on the topic, only typically developing participants have so far been tested for temporal relational responding, so the generalizability of these findings to other populations is not clear. In some populations such as autistic children, there may be delays with respect to learning of these key repertoires and in these cases targeted training of temporal relations may be needed. Previous research has shown that individuals with developmental or intellectual disabilities can demonstrate deficits in various forms of relational responding (Barron et al., 2019; Gilroy et al., 2015; McLay et al., 2013; Moran et al., 2015; Rehfeldt et al., 2007) and it is possible that this might apply to temporal relations also. Outside of the behavior analytic literature, Overweg et al. (2018) also found that autistic children were less accurate overall in comprehending sentences containing the temporal terms “before” and “after” compared with their typically developing peers.

A second limitation of the current literature is that no training approach has specifically improved responding with temporal relations when absent or deficient. While research evaluating and teaching temporal relational responding specifically for children with developmental disabilities has not yet been conducted, research has examined the utility and efficacy of an RFT approach for assessing and teaching other relational skills for autistic children (Barron et al., 2019; Belisle et al., 2016; 2020; Gilroy et al., 2015; Kirsten et al., 2022a; Ming et al., 2018). Hence, the RFT framework may be successful in addressing deficits that children with developmental disabilities may have in temporal relational responding by establishing and strengthening this repertoire through multiple exemplar training (MET).

From this perspective, assessing and teaching temporal relational responding is critical to supporting and boosting children’s temporal understanding. The aim of the present study was to evaluate the efficacy of an assessment and teaching procedure based on an RFT framework to establish and strengthen a foundational level of nonarbitrary temporal relational responding in three autistic participants. Consistent with interventions teaching other relations, the present study used a MET procedure to establish this skill in those children showing a relative deficiency and tested for generalization of the skill. This study was also conducted over telehealth. As MET materials for teaching relational responding can often be efficiently presented in a digital format, delivering instruction in a telehealth format was considered a unique opportunity that has minimally been explored in applied RFT research.

Method

Participants

Informed assent and consent were obtained from the three participants and their parents, respectively. Before the study began, pseudonyms were applied instead of their actual names. Participants were three adolescents previously diagnosed with autism by a relevant professional in accordance with the Diagnostic and Statistical Manual of Mental Disorders Fourth Edition (American Psychiatric Association, 2000). Katie (15-year-old female), Anna (17-year-old female), and Jack (18-year-old male) were all enrolled in a special education school in the West of Ireland. All participants were performing at Level 2 on the Verbal Behavior Milestones Assessment and Placement Program (VB-MAPP; Sundberg, 2008) at the time of the present study. Participants communicated primarily using short and succinct sentences. When presented with yes or no questions, the participants responded accurately and often extended their answers to provide further detail. Participants had the ability to report on events of their day or previous times when prompted. None of the participants had received previous assessment for or teaching in temporal relational responding.

The criteria for inclusion in the study included: (a) diagnosis of autism; (b) prerequisite skills including accuracy in answering Yes/No questions; (c) ability to label common items; (d) ability to follow multi-step instruction; (e) failure to score 100% accuracy on an assessment probe for temporal NARR; and (f) an internet connection and equipment required to support telehealth delivery for the duration of the study. Prior to commencement of the study, parents received written information on their and their child's rights as study participants, an information sheet on the procedure of the study, consent and assent forms, and a Note of Privacy Practices in relation to encrypted two-way video calling being used in the study.

Setting

All sessions were conducted online via the use of a home-based laptop with a built-in web-camera and microphone linked via Zoom. The researcher followed a set of ethical guidelines for practice with online delivery of interventions adapted from Trepal et al. (2007) in addition to a second independent observer scoring a procedural reliability checklist (Davlin et al., 2011). Participants and their parents were familiar with the use of laptops and video-calling. Sessions were conducted with the participant sitting at a desk in a quiet room in their home. Each participant completed sessions using a laptop provided by their family and each participant additionally wore headphones throughout each session to minimize any potential background noise within their home. For an active participant (i.e., in continuous baseline or training phases), sessions were conducted once daily on weekdays. Session duration ranged from 10-15 min, with longer sessions reflecting more breaks being requested by the participant. For the remaining participant(s), baseline probe data were collected on the application of intervention to the preceding participant. The intervention was conducted during extended school break and the primary researcher estimated the total duration of participation for each of the participants during this time including both initial assessment and post-training measures to be no longer than six weeks.

Materials

All materials used during screening, baseline, training, maintenance, and generalization sessions were presented from a 13-inch HP Pavilion I3 laptop on Microsoft PowerPoint presentations via the screen share feature of Zoom. Test and training stimuli included known images of common items (correct labeling of such stimuli was a prerequisite skill included in the pre-test). The images of common items were categorized into animals, household objects, colors, personal items, and leisure activity materials. For baseline and training sessions, 50 stimulus exemplars were used (10 images per category). For generalization sessions, twenty novel exemplars were used. Ten of the novel exemplars were used for the first generalization session (2 images per category) and the other 10 novel exemplars were used for the second generalization session (2 images per category). Exemplars were of uniform size on PowerPoint 5 x 5 cm and were enclosed in a black square. Exemplar pairings were randomized prior to each session by the experimenter shuffling the slide deck into a novel order.

Dependent Measures

In baseline, intervention, post-training, and generalization phases, the dependent variable was the percentage of correct responses on nonarbitrary temporal relational responding trials. There was a total of 30 trials in each session, consisting of two different categories of trial-type[8]. Twenty trials posed the question "What was before/after?" On this trial-type category, a correct response was scored if the participant vocally tacted the name of the stimulus that was either before (10 trials) or after (10 trials) the other stimulus as required. The remaining 10 trials consisted of a question such as, "Was the house before the swing?" or "Was the cat after the shoe?" to which either a "Yes" or "No" response was required (5 trials with "yes" as the correct answer and 5 trials with "no" as the correct answer). A correct response was scored on this category of trial type if the participant gave a vocal "Yes" response when the relational statement accurately described the observed image sequence or a vocal "No" response when the relational statement did not describe the observed image sequence respectively. For all trials, a response was only considered correct if it occurred in the absence of prompts. Trial order was varied in each session. The specific order was decided by the researcher prior to the onset of each session to ensure that the correct number of trials were presented per trial-type.

Interobserver Agreement and Procedural Fidelity

[8] The rationale for teaching multiple response forms was to help facilitate a more flexible relational response repertoire. While teaching the core relational response pattern is critical, it is also important to promote generalization to different contexts such as various task formats (Barnes-Holmes et al., 2001). Both trial types used were from the nonarbitrary temporal relations section in Kirsten et al. (2022) and incorporating multiple response forms has been suggested in previous RFT research to provide a more thorough indication of the relational repertoire (Neufeld et al., 2023).

A second independent observer scored responses in 69% of sessions to assess for interobserver agreement (IOA). Trial-by-trial IOA data were calculated by taking the number of agreements and dividing by the total number of disagreements and agreements, then multiplying it by 100. IOA was calculated in 62% of baseline sessions, 60% of MET sessions, and in 100% of post-training and generalization sessions across participants. The second observer was a teacher who received training from the primary researcher on response measurement for the procedure. The overall agreement across all sessions and participants across each condition was 100%, corresponding with an overall average of 100% IOA. Procedural fidelity data were also collected by an independent observer. The procedural fidelity measure was adapted from Davlin and colleagues' (2011) checklist. The measure included whether the researcher conducted pre-session video conferencing checks, randomized the presentation of exemplars and question type, correctly phrased and delivered questions, followed prompting, reinforcement, and error correction procedures, recorded participant responses, ensured availability of breaks throughout the session by the presence of a break-card beside the participants' laptop, and delivered additional structured breaks during training trials. Procedural fidelity was assessed alongside IOA in the same sessions (i.e., 69% of sessions across conditions) and the researcher was observed to implement the program correctly in 100% of the sessions observed.

Design

A multiple probe design (MPD) across participants was selected for this study to evaluate the functional relation between MET and skill acquisition (Ledford & Gast., 2018). The target skill in intervention was nonarbitrary temporal relational responding between exemplars. The MPD design utilizes multiple probes for baseline data, in comparison to continuous simultaneous baseline data for each participant (Cooper et al., 2020). This design was selected to minimize threats to internal validity and reduce participant exposure to temporal relational responding assessments (Ledford & Gast., 2018). Lengthy concurrent baselines would have been unnecessary and increase the potential for frustration and/or fatigue (Gilroy et al., 2015). Furthermore, the MPD design was most appropriate to the setting, in relation to resources required to facilitate measurement of continuous baselines (Horner & Baer, 1978). Criteria for moving subsequent participants into the training phase was dependent on the preceding participant meeting mastery criteria of 100% across 2 consecutive sessions.

Procedure

Prior to the onset of each session, the instructor and a family member checked the internet connection, and audiovisual and screen sharing features to ensure they were fully functional to prevent any disruptions during sessions. The instructor then requested that the family member turn off any other screens in the room that the participant was conducting sessions in if relevant. Once all connectivity and audiovisual functionality was confirmed, the family member remained in the room throughout the session. Family members were instructed to not provide guidance to the participant on how to respond and were asked to aid only in the case of technical support.

Temporal Relations Assessment

Following initial screening and testing for relevant prerequisite skills, participants completed an adapted version of the temporal relational responding assessment from Neufeld et al. (2023) to determine inclusion. The adapted temporal relations assessment included tests for temporal NARR (composed of 18 trials of 2-image sequences and 18 trials of 3-image sequences) and temporal AARR (composed of 28 trials for mutual entailment, 28 trials for combinatorial entailment and 28 trials for transformation of function). If a participant scored 100% correct across all nonarbitrary trials, their participation in the study concluded. The first nonarbitrary section at which the participant failed to achieve 100% accuracy was then set as target skill for intervention (i.e., 2-image sequences or 3-image sequences). The termination criterion for the assessment was at the stage at which the participant failed to achieve 100% accuracy.

Baseline

Participants were exposed to baseline measurement based on the order of performance on the temporal relational responding assessment, starting with the participant performing lowest overall. During baseline session trials, the experimenter presented a sequence of two stimuli. Each stimulus was presented on screen for 1 s (e.g., an image of a house appeared on screen for 1 s, followed by a blank screen for 1s, followed by an image of a swing for 1 s, followed by a blank screen). The experimenter then asked the participant a question regarding the nonarbitrary temporal relation between the stimuli presented (e.g., “What was before/after?” or “Was the house after the swing?”). Baseline procedures were similar to training trials, with the exception that the participant was not provided with any differential consequences for correct or incorrect responses. Precisely, during baseline, following the participant’s response, the experimenter said “Okay,” in a neutral tone. A session ended once each of the 30 trials was presented. Baseline measurement continued until three consecutive observations of stable responding or trending in the opposite direction to learning were observed. Non-consecutive baseline probes were collected for remaining participants coincident with the preceding participant(s) moving into the training phase.

Intervention

Prior to starting the training sessions, the participant selected a preferred activity to access on completion of the session. As in baseline, the session was composed of the same 30 trials, assessing nonarbitrary temporal relations between two stimuli. During the training phase, procedures of reinforcement, error correction, and prompting were used. If the participant provided the correct answer, immediate verbal praise was delivered, and the participant was awarded a virtual sticker (i.e., an emoji icon appeared on-screen)[9]. If the participant emitted an incorrect response, the researcher

[9] Since the study was conducted via telehealth, these icons were included to complement social praise to make the feedback more interactive. We reasoned that when an intervention is delivered in-person, other contextual features like facial expression, etc. may be more salient compared to when delivered on a computer screen. Accordingly, we attempted to provide a visual component to the feedback in addition to the auditory feedback.

said, "Nice effort but let's try it again," and then presented the trial stimuli again while verbally labeling the preceding stimulus as "before" and the following stimulus as "after." The researcher then re-delivered the question. If the participant still did not answer correctly, the researcher presented the trial once again and this time delivered a full-vocal prompt for the correct answer (i.e., the researcher modeled the "yes" or "no" response or stated the name of the image that came before/after). Training continued until they met the pre-determined criterion of 100% correct responding across two consecutive sessions. Following the first participant meeting the pre-determined criteria in training, continuous baseline measurement for the subsequent participant began. This procedure was applied in the case of all three participants. Additional baseline probes for the remaining participant(s) were taken coincident with the staggered introduction of the intervention for preceding participant(s).

Post-Training and Generalization

Each participant entered a post-training phase following mastery in the MET phase. Each participant received two post-training sessions scheduled for approximately two- and four-weeks following training, respectively. Conditions in post-training phase probes were identical to that of baseline with no error correction or prompting provided. Once criterion was met in the MET phase and each post-training probe was completed, generalization was assessed across two novel stimuli sets. Conditions in the generalization phase were almost identical to baseline and post-training with the difference being that novel exemplars were utilized to evaluate generalization of the repertoire. No prompting, error correction, or reinforcement was given in this condition, but instead, the researcher provided a neutral response following each trial as in baseline sessions.

Results

Temporal Relational Responding Assessment

Prior to baseline probes and continuous baseline measurements, participants completed a temporal relations assessment to determine their existing level of temporal relational responding. The two-phase assessment was of increasing difficulty and criterion to progress to the subsequent phase was achieving 100% accuracy on the preceding phase. Each participant scored below 100% accuracy on the first stage of the assessment: temporal NARR with 2-image sequences. On this section, Anna scored 39% correct, Jack scored 40% correct, and Katie scored 44% correct. As 100% accuracy was not achieved on this initial stage of the assessment, the remaining assessment sections were not administered, and temporal NARR with 2-image sequences was set as the target skill for each participant.

Multiple Probe Design: Overview

Performances for all three participants are graphed as percentage of correct responses during baseline, intervention, post-training, and generalization phases is shown in Figure 1. For each participant, stable responding was observed below 50% accuracy across all baseline sessions. Following the introduction of MET, substantial and steady improvements in nonarbitrary temporal relational responding were observed across all participants until mastery criterion was achieved. In contrast to baseline data, scores greatly increased during intervention with a consistent upward trend reaching 100% accuracy across two consecutive sessions. Similarly, during post-training and generalization probes, performance for all three participants remained at mastery levels demonstrating that performance generalized to novel exemplars and maintained post-training.

Individual Participant Data

Anna

Anna demonstrated low levels of accuracy during baseline measurement scoring on average 36% correct (range 33-39% correct), as shown in Figure 1. Fifteen sessions were required for Anna to reach the mastery criterion of 100% correct across two sessions for the target skill. Post-training phase was entered following mastery being achieved; Anna continued to exhibit high levels of accuracy during post-training scoring 100% correct across both probe sessions. The difference in correct responses between baseline and post-training phases was high, shown in the comparable data trends from baseline (36% average correct) to post-training phases (100% average correct). When tested during the generalization probes, Anna responded at 100% correct across each of the two novel exemplar sets.

Jack

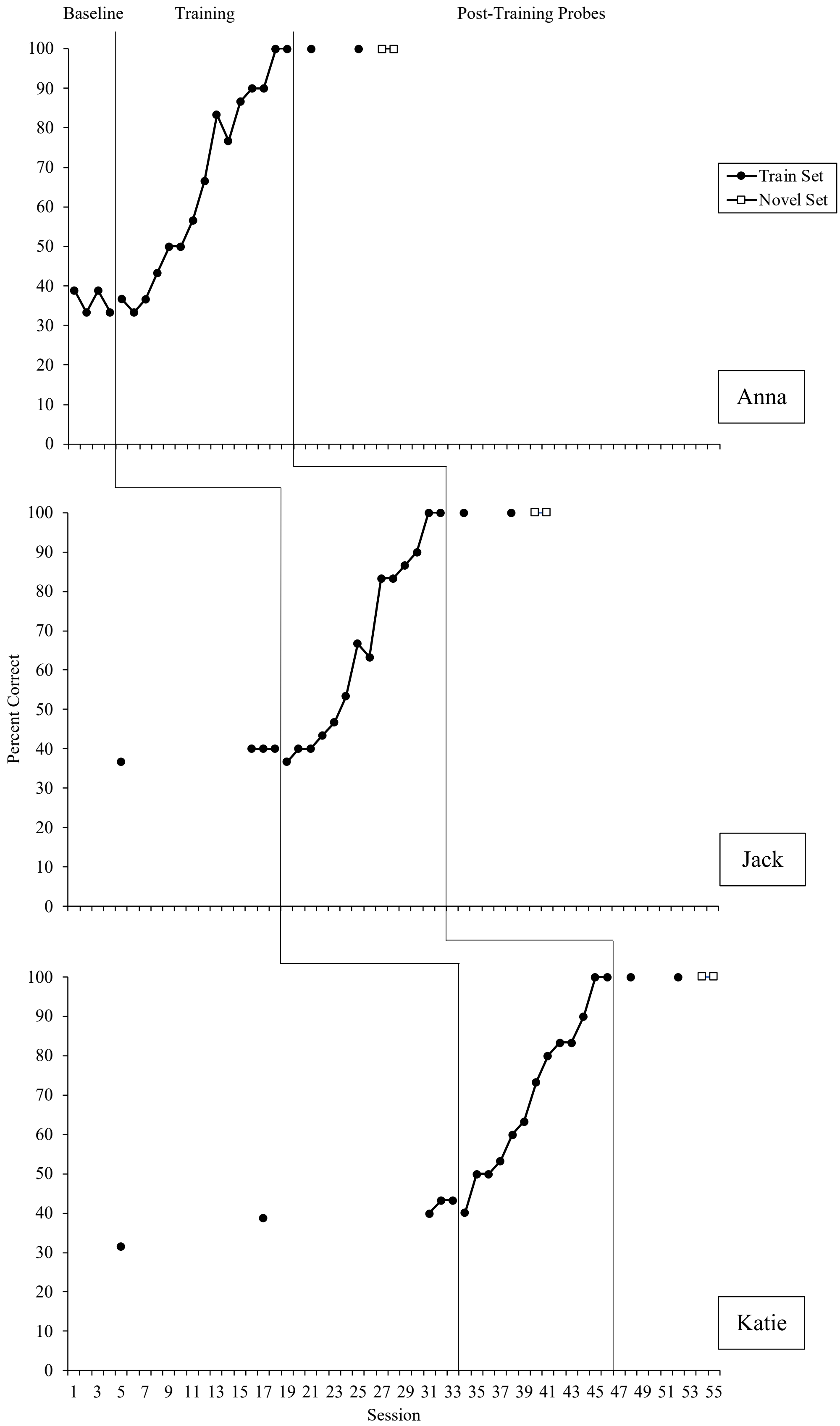
Jack also demonstrated low levels of accuracy in nonarbitrary temporal relational responding during baseline measurement scoring an average of 39% correct (range 37-40% correct). Fourteen training sessions of MET were necessary for Jack to meet mastery criteria. There was a large difference in performance, from baseline (39% average correct) to post-training phases (100% average correct) which is demonstrated in the data change. Mastery of the skill was maintained at post-training and generalization was observed on each of the two novel exemplar sets, with Jack scoring 100% correct in both phases, respectively.

Katie

Baseline probe data were collected for Katie when each of the two preceding participants entered the intervention phase. During baseline measurement, Katie scored on average 39% correct (range 32-43% correct) Katie required 13 training sessions to meet mastery criterion. During the post-training phase, Katie scored 100% correct across both sessions. Katie subsequently passed tests for generalization, scoring 100% correct with both novel sets of stimuli. The magnitude of difference in accuracy from baseline to post-training phases was high, from 39% correct in baseline phases to 100% correct in generalization probes.

Figure 6.1

Percentage Correct on Nonarbitrary Temporal Relations Trials across All Phases for All Participants



Discussion

The present study assessed and trained nonarbitrary temporal relational responding in three autistic adolescents. RFT research has suggested that relational responding deficits may be present in autistic individuals relative to their neurotypical peers (McLay et al., 2013; Rehfeldt et al., 2007). The present study focused specifically on nonarbitrary temporal relations, which may be considered a key foundational skill for more complex, derived temporal relations. This study successfully trained this skill using multiple exemplar training (MET), thus indicating the potential efficacy of this intervention in this context.

Data were collected prior to and following MET. Each participant maintained low levels accuracy during the baseline condition. As MET was introduced, each participant demonstrated improvements in responding and subsequently met the training criterion. A high level of accuracy was maintained in each participant two- and four-weeks following completion of training. Participants were then tested for generalization, and each showed a high level of performance with two sets of novel stimuli exemplars. In summary, performance to the mastery criterion was achieved, maintained, and generalized by all three participants following completion of the MET phase for nonarbitrary temporal relational responding.

The results of the present study extend existing research suggesting that MET is an effective method of establishing and strengthening relational responding (Belisle, Stanley, et al., 2020; Berens & Hayes, 2007; Kirsten et al., 2022a; Ming et al., 2018; Mulhern et al., 2018). This research also provided the first empirical evidence for MET as an effective intervention for teaching temporal relational responding to autistic individuals. Specifically, this approach was effective in teaching three autistic participants to respond to nonarbitrary temporal relations between various exemplars with "before" and "after" contextual cues. As research to date has minimally investigated training temporal relations in autistic individuals, these data have important implications. From an RFT point of view, establishing and strengthening temporal relational responding in autistic children should ultimately result in substantial benefits as it is a fundamental skill which underpins a range of functional living and social skills including sequencing, talking about the past and future, and time management. These more complex repertoires are pivotal across personal, academic, and occupational settings. First learning to relationally respond to actual event sequences in the presence of "before" and "after" contextual cues represents an arguably important foundational skill to building these more complex repertories.

The current study furthers existing research on temporal relational responding in two primary ways. First, existing research on temporal relational responding has thus far only included neurotypical children (Neufeld et al., 2023), and has predominantly been limited to work neurotypical adults (Brassil et al., 2019; Hyland et al., 2012; 2014; McGreal et al., 2016; O'Hora et al., 2005; 2008; 2014). The present study expands the literature base to include autistic participants with demonstrated deficits of this repertoire. Second, existing research on temporal relational responding has not included a training component when this repertoire is absent or deficient. While there has been research using MET to train autistic children on other nonarbitrary relations, such as nonarbitrary sameness (Belisle, Huggins, et al., 2020; Toussaint et al., 2017) and hierarchy (Ming et al., 2018), no work has been done with temporal relations. The present study addresses this limitation by specifically demonstrating the effectiveness of a MET approach to training nonarbitrary temporal relations. Considering that mastery of abstract time concepts unfolds over several years in childhood (Friedman, 2000; Friedman & Kemp, 1998; McCormack & Hoerl, 2017; Moore et al., 2014; Pyykkönen & Järvikivi, 2012; Tillman et al., 2022), developing effective training approaches for populations that may have difficulty acquiring these skills is critical. Further research is warranted in this area to support the findings of the present study and to refine the efficacy of the training protocol.

Additionally, the present study expands the literature on nonarbitrary relational responding in humans more generally by providing initial data on nonarbitrary temporal relations. Research on responding to nonarbitrary stimulus relations in nonhumans has accumulated over several decades (Flemming et al., 2007; Ghirlanda et al., 2017; Harmon et al., 1982; Thompson & Oden, 2010; Truppa et al., 2011). However, research with humans on nonarbitrary relations beyond sameness has not necessarily been as extensive (Ming & Stewart, 2017). Considering the potential relevancy of the acquisition of nonarbitrary relations to more complex verbal repertoires, more work is needed not just with temporal relations but other nonarbitrary relations as well. Although some behavior analytic curricula, such as the Promoting the Emergence of Advanced Knowledge (PEAK) Relational Training System (Dixon, 2015, 2016) have begun incorporating nonarbitrary relational responding into their training designs, more empirical work in this area is needed.

The present study also administered the intervention via telehealth which is an increasingly popular method for behavioral service delivery. Telehealth and online learning platforms have been found to reduce the barriers autistic children face between intervention requirements and the availability of resources and intervention (Vismara et al., 2013). Prior to the global pandemic, during which the current study was conducted, research was beginning to highlight the need for telehealth to be utilized in greater abundance in providing behavior analytic interventions (Ferguson et al., 2019), clinical assessments (Dahiya et al., 2020), professional and parent training for autistic children (Wainer & Ingersoll, 2011), and supporting behaviours of concern (Lindgren et al., 2016). This study supports findings of other applied behavior analytic research which has used telehealth for the delivery of various skill teaching assessments and interventions (Gibson et al., 2010; Neely et al., 2017). As teaching and learning has been shaped indefinitely by safety procedures in place following the pandemic, research utilizing telehealth successfully with positive treatment outcomes is fundamental to the progression of the field.

Limitations and Future Research

One limitation of the study is that the degree to which the skill generalized to everyday language and related repertoires was not assessed. As the purpose of this study was to provide preliminary insight into temporal relational responding in autistic participants and whether MET would be effective in training this skill, generalization was only assessed across novel exemplar sets. The extent to which the skills strengthened in the current study generalized to the participants' everyday lives is unknown, yet the fact that generalization occurred across novel untrained stimuli sets provides encouragement for further research. Subsequent studies should include additional tests for generalization and examine whether improvements in this skill relates to other relevant repertoires (e.g., sequencing tasks, following multi-step directions). Such work is critical to expanding our knowledge regarding temporal relational responding and its relation to time understanding.

Future research could also explore additional generalization considerations, such as assessing the skill with novel instructors or in other settings. Although the current study was delivered in an online format, its structure is transferable to in person teaching also and a comparative study examining the two methodological approaches may be insightful with relation to the generalizability of the findings. Although generalization of the target skill was achieved across two novel exemplar sets in the current study, inclusion of an additional condition with a novel instructor would have been beneficial as generalization across new instructors could lead to benefits beyond the academic setting over time. However, due to the online delivery of the intervention and restrictions due to the global pandemic, training and delivery of generalization conditions by a novel instructor was not possible.

Another direction future research could take involves expanding the training program to include shifting contextual control to arbitrary temporal relations. The present study did not include arbitrary temporal relations, as the primary aim was to assess and train the more foundational skill of temporal NARR. However, learning to derive arbitrary temporal relations is particularly relevant to more complex verbal repertoires such as rule-following, problem solving, and responding to delayed consequences. This could be included in training for autistic populations. Studies involving other patterns of relational responding have shown the benefits of using nonarbitrary relations to acquire more abstract relations (Barnes-Holmes, Barnes-Holmes, Smeets, et al., 2004; Berens & Hayes, 2007). It is plausible that this may apply to temporal relations as well, but this should be explored empirically.

Lastly, future research could expand on the current study by including other demographics, forms of measurement, and additional contextual cues. The present study included only three autistic adolescents. This training could be replicated with autistic children of varying ages to examine the utility of the intervention more closely in other contexts. Future work should also include a measure of social validity to assess significance and acceptability of the training procedures. Additionally, the current study only used "percent correct" as a dependent measure. Existing studies involving nonarbitrary temporal relations with adults have also included response latency, which have shown that adults are faster on "before" compared to "after" trials (Hyland et al., 2012). As the current study did not include response latency, it remains uncertain whether the participants a) responded in a similar pattern, and b) if training affected this dimension of behavior. Future research could replicate the training protocol and additionally include a measure of response latency. Further, the current study only included total accuracy across the trial blocks. Future research should consider examining any differences in responding based on the response form (i.e., between tacting the stimulus that was before or after vs yes/no responding about a description of the observed sequence). This might add to data concerning young children's acquisition of temporal relations as well as relational responding more generally. Finally, potential future work could incorporate other contextual cues for temporal relations. While the contextual cues included in the present study ("before/after") are important, children encounter a range of other cues, (e.g., "earlier/later", "first/last") in natural environments. Future research should investigate performance with these different contextual cues and how to incorporate them in training designs to expand relational skills in learners.

Conclusion

The present study complements and extends the results of existing temporal responding research, in that participants were autistic individuals who were assessed and trained successfully in nonarbitrary temporal relational responding with "before" and "after" cues using an RFT based approach. It contributes to the literature on relational responding by suggesting that autistic children exhibit deficits in temporal relational responding and that such deficits can be successfully addressed through MET. Such findings extend support for the position that MET is an effective training methodology for teaching relational responding in neurotypical and neurodiverse children alike. The social validity of assessing and addressing deficits in temporal relational responding for autistic children is substantial as the skill is fundamental to temporally ordering events, and other time understanding skills. The present results are encouraging as they indicate that deficits in nonarbitrary temporal relational responding can be successfully addressed in autistic adolescents. Continued research in this area is needed as such work is critical to expanding our knowledge regarding how the acquisition of verbal repertoires relate to an abstract understanding of time.

Chapter 7.
General Discussion

The purpose of this research program has been to extend research on temporal responding and more specifically understanding of time, using an RFT approach. Towards this end, this research has identified areas of application of RFT relevant to temporal skill sets; extended research on temporal relations to new demographics; designed an assessment procedure to measure performance on temporal relational tasks; and developed a training procedure that can be used to facilitate the acquisition of these repertoires. In the final chapter of this thesis, I provide an overview of the work that has been done and discuss implications and directions for future work. This chapter first provides an overview of key findings from the literature review and Studies 1-4, followed by the theoretical and applied implications from this research. Following this, a discussion of the limitations and directions for future research is provided.

Overview of Thesis

Narrative Review (Chapter 2)

Historically, behavioral research has examined temporal responding in terms of responses to various durations in context of different reinforcement schedules. For instance, research has shown that humans demonstrate response patterns that differ from nonverbal organisms on FI schedules of reinforcement (Lowe et al., 1978) and that this difference becomes more pronounced during childhood (Bentall et al., 1985). Other work has shown that providing training with temporal instructions can improve performance with reinforcement schedules (Droit et al., 1990) and timing tasks (Lejeune et al., 1992). However, no behavioral work has specifically examined how verbal abilities alters our experience with time.

RFT suggests that due to AARR, humans additionally experience time in a fundamentally different way. That is, humans experience a “verbal time.” Instead of solely discriminating and responding to moment-to-moment changes in the environment, humans verbally create bidirectional sequences about the past or future without having had to experience them directly. One important pattern of AARR relevant to verbally responding to time is temporal relational framing. This frame can be made more precise through quantification, shares overlapping features with certain frames (e.g., comparison, spatial, deictic, causal), and is often involved in forming rules. Conceptually, it reasons that AARR more generally and temporal AARR more specifically are relevant for the acquisition of and performance with time-related skill sets. Chapter 2 sought to identify multiple areas of investigation in which RFT could potentially offer a new or supplemental approach that would advance our understanding of human temporal responding.

Temporal skills range from basic to complex, including skills such as temporal sequencing, timing, using conventional time systems, self-control, planning, and time management. Research with temporal sequencing has revealed gradual improvements with age (Fivush & Mandler, 1985; Friedman, 1990), although a question for continued exploration is to what degree does “before” and “after” understanding facilitate performance on these tasks (McCormack & Hanley, 2011). An RFT approach can augment this work as it precisely pinpoints how to operationalize and train "understanding" of these words. Research with timing has shown that explicit timing improves with age (Droit-Volet & Coull, 2016), there is an increased reliance on counting strategies as children acquire verbal skills (Wilkening et al., 1987) and changing contextual features can distort duration estimates (Droit-Volet & Gil, 2009). RFT-based work might seek to investigate whether training equivalence relations between quantities and durations improves timing and whether facilitating stimulus function transformations alters duration estimates.

Mastering the use of the clock and calendar systems takes years in childhood and gradual improves have been observed with telling time (Friedman & Laycock, 1989), acquiring duration and deictic time words (Tillman et al., 2015; 2017), and using calendar information to talk about events (Tartas, 2001). One key area for RFT application includes embedding relational learning into clock and calendar instruction, such as by teaching the various ways that conventional time words can be related. Research on self-control has found multiple behavioral approaches that alter responding toward delayed reinforcers (Whiting & Dixon, 2015) and notably, future-oriented manipulations have shown to affect delay discounting (Scholten et al., 2019). RFT provides an approach that could help investigate verbal interventions, such as with forming self-control rules, interpreting future-oriented strategies behaviorally, and transforming the functions of immediate and delayed choices (Dixon & Holton, 2009). Lastly, research on planning has shown age-related improvements on both in-the-moment (McColgan & McCormack, 2008) and hypothetical-future planning tasks (Atance & Meltzoff, 2005); while work with time management is scarce. RFT-based work could look at identifying which relational frames are most relevant at different points during planning tasks (Tyrberg et al., 2021), and embed specific relational response training during planning and time management instruction.

Study 1 (Chapter 3)

Existing research on derived relational responding has primarily examined relations of equivalence (O'Connor et al., 2017). Although investigations of nonequivalence relations have continued to expand over the now 40-year history of RFT, temporal relations have still received little empirical attention. Accordingly, the primary aim of Study 1 was to investigate young children's performance on tasks of temporal relational responding at different levels of complexity. Twenty-five children between 3-8 years were assessed on performance with nonarbitrary temporal relations with 2- and 3-image stimulus sequences, arbitrary mutually and combinatorially entailed temporal relations, and transformation of function in accordance with arbitrary relational networks.

Results from Study 1 highlighted two key findings. One, the data showed that temporal NARR appeared to be acquired earlier than temporal AARR. A high level of accuracy (80% mean accuracy) on the nonarbitrary temporal relations tasks appeared to emerge between 5-6 years of age. In contrast, no age cohort demonstrated this level of accuracy on the presented arbitrary temporal relations tasks. Existing RFT literature has discussed that NARR may be a particularly important precursor skill to AARR (Stewart & McElwee, 2009). Empirically, evidence for this has been found with other nonequivalence relations such as comparison (Berens & Hayes, 2007) and hierarchy (Mulhern et al., 2017). The results of the current study provide tentative support that this may be true for temporal frames as well. However, replication is warranted with a larger sample size and additional assessment conditions.

A second notable finding was that there were varying differences in performance observed for NARR and AARR in responding toward "before" and "after" contextual cues. On the temporal NARR tasks, participants generally responded with comparable levels of accuracy with both contextual cues across ages. This was not the case for temporal AARR tasks. Participants regularly responded with greater accuracy on trials with "before" as the displayed contextual cue compared to trials with "after" as the displayed contextual cue for. Further, this finding was consistent across tests for mutual entailment, combinatorial entailment, and transformation of function. Whereas accuracy on arbitrary "before" trials improved with age, accuracy on "after" trials did not.

Studies 2 and 3 (Chapters 4 and 5)

The aim of Studies 2 and 3 was to develop and refine an RFT-based training protocol to train arbitrary temporal relations (i.e., temporal relational frames) in young children. Multiple studies have shown that MET can be used to improve various patterns of AARR in children when these repertoires are still emerging (e.g., Dunne et al., 2014). However, no existing work had specifically taught temporal AARR with the contextual cues "before" and "after." The data obtained from Study 1 revealed response patterns across different ages on different tasks of temporal relational responding, which informed participant selection for intervention. Specifically, by 5-6 years of age, children tended to respond with a higher level of accuracy on temporal NARR tasks but did not pass tests for temporal AARR.

Study 2 was an initial investigation into the efficacy of a MET intervention for arbitrary temporal relational responding. Guided by findings in Study 1, two 6-year-olds were trained on temporal AARR with mutually and combinatorially entailed relations in a nonconcurrent combined multiple baseline design. The study included a screening of potential prerequisite skills; a baseline condition in which temporal AARR was assessed across multiple stimulus sets; an intervention of the targeted relations with one stimulus set; and generalization and maintenance testing across all stimulus sets. Results showed that both participants demonstrated contextually controlled responding with both "before" and "after" cues with the trained set of stimuli. MET was generally effective for both participants; however, one participant required a training condition in which the contextual cues were isolated from one another, and multiple stimulus sets to reach criterion. Both participants showed generalization to novel stimuli and maintained this performance post-intervention.

Study 3 was an extension from Study 2 and attempted to address some of its limitations. Namely, a stronger experimental design was used, and additional responses (ToF trials) were trained in slightly younger participants. Study 3 employed a combined multiple probe design across participants and responses to train temporal relational framing (mutual entailment, transformation of function via mutual entailment, combinatorial entailment, and transformation of function via combinatorial entailment) in accordance with “before” and “after cues” in three neurotypical 5-year-olds. Additionally, Study 3 attempted to improve the efficiency of the protocol developed in Study 2 by reducing the number of trials required. A similar MET training approach was used as in Study 2 while the stimuli selected for the arbitrary relational networks (colored shapes) and transformation of function trials (images of motor actions) mirrored the format of Study 1. Baseline, training, generalization, and maintenance conditions across each repertoire were again included. As in Study 2, participants reached training criterion across repertoires following MET and showed generalized responding to novel exemplars. During the post-training condition, not all responses for every participant were maintained at the same level as compared to training (e.g., transformation of function via combinatorial entailment for P1). However, overall accuracy was maintained at a higher level than baseline for each participant.

Taken together, Studies 2 and 3 both showed that responding can come under contextual control with arbitrary contextual cues for temporal relations. In both studies, participants demonstrated mutual entailment and combinatorial entailment following MET. Each participant in Study 3 additionally learned to sequence sets of motor actions in accordance with arbitrary relational networks following intervention (i.e., a transformation of stimulus function). Both Studies 2 and 3 showed a similar response pattern as had been observed in Study 1: a much stronger baseline performance with arbitrary “before” trials compared to “after.” Following intervention, a notable increase in accuracy with “after” trials was observed and participants responded in accordance with both contextual cues.

Study 4 (Chapter 6)

Study 4 sought to extend this line of research to another demographic. Some existing research has identified that individuals with autism may present with deficits in AARR (McLay et al., 2013; Rehfeldt et al., 2007) and that they may have greater challenges understanding temporal terms compared to their same age neurotypical peers (Overweg et al., 2018). Moreover, prior studies have shown that MET has been effective in training relational responses in individuals with autism for both nonarbitrary relations (Ming et al., 2018) and arbitrary relations (Belisle, Stanley, et al., 2020). However, no work prior to this research program had investigated the acquisition of “before” and “after” relations in neurodiverse populations.

In Study 4, a multiple probe design was used to teach nonarbitrary temporal relational responding in three autistic adolescents. Each participant was first assessed using an adapted version of the temporal relations assessment that was used in Study 1. The first nonarbitrary test section in which criterion was not met was the targeted skill for intervention, and in the case of all participants this was temporal NARR with 2-image sequences. MET was used in which a variety of 2-image stimulus sequences were presented, and differential reinforcement was applied for responding in accordance with “before” and “after” cues. The outcomes were that all participants met training criterion, maintained performance post-training, and passed generalization tests with two novel stimulus sets.

Although Study 4 is limited insofar as it solely trained nonarbitrary temporal relations, it is still an important contribution. RFT emphasizes that a generalized AARR repertoire is the key operant relevant to complex human behavior but nonetheless, learning NARR across relational patterns is an important building block. Existing research on training procedures for nonarbitrary relations other than sameness (identity) is minimal. Continued work in this area may offer insight into intervention design, scope, and sequence with relational skills. If individuals have yet to acquire these more foundational relational skills (as was the case for participants in Study 4), this would be the logical point of introduction for training. Further, learning to respond to formal temporal relations in the presence of contextual cues used within the learner's socioverbal community may assist with effectively navigating sequences in their environment. Indeed, the distinction between NARR and AARR may become blurrier in naturalistic contexts as instances of relating may often be nonarbitrarily applied. For example, calendars or written activity-schedules that include "before" and "after" cues involve arbitrary stimuli, but these schedules are often tied to real events that are actually sequentially experienced.

Overall Contributions and Implications

Collectively, the totality of this research program included a review and conceptual RFT analysis of temporal skill sets, and the assessment and training of temporal relational responding repertoires in neurotypical children and autistic adolescents. This section describes the overarching contributions of this thesis to the literature, and the theoretical and applied implications for behavioral and nonbehavioral approaches to the acquisition of temporal relations.

Most notably, the current work addresses a pressing need concerning the lack of research on temporal relations identified in the RFT literature. To put this into perspective, consider the following quotes from RFT textbooks:

> "The impact of such verbal temporal relations on how humans interact with their environments is immense." (Hayes, Fox, et al., 2001, p. 60)."
>
> "Though we have acquired substantial evidence of the importance of framing in general to language and cognition, research into framing at a more detailed level is still at a relatively early stage. For example, there remains as yet little or no investigation of some unquestionably important forms of framing (e.g., spatial, temporal, logical or hierarchical) and as yet limited investigation of some others (e.g., conditional, sequential)" (Stewart, Tarbox, et al., 2013, p. 192)."
>
> "Unfortunately, evidence of temporal framing and the history of learning needed to establish it is currently scarce. This class of relations has received far less attention than other frames in the RFT literature, with existing work focused on their implications for intelligence and rule-following, as well as their experimental induction in adult populations…It remains to be seen how these frames are initially established in the natural environment, how the unidirectional experience of change comes to be abstracted, and the bidirectional dimension of time constructed. Given their potential role in suicide (Hayes, 1992) and delayed gratification (Mischel & Ayduk, 2004), for example, closer attention to temporal relations certainly seems warranted" (Hughes & Barnes-Holmes, 2016, p. 153).

> "To date, temporality has commonly been combined with other relational frames and has rarely been targeted as a relational frame in isolation within applied research with children and populations for whom this relational repertoire may be deficient…Given the frequency with which temporality is cited within the introduction of published RFT work (and indeed, the importance of the concept of time itself), it is surprising that there remains a dearth of literature which focuses on temporality alone….to date, there is no research which has focused on the facilitation of temporal relations amongst individuals who demonstrate deficits in this repertoire… The lack of published research which focuses on the facilitation of non-arbitrary and arbitrary temporal relations with populations deficient in this repertoire indicates a substantial gap in the area which future research should aim to resolve." (Mulhern, 2023, pp. 131, 145, 149).

A sobering insight from the sequence of these passages is that the importance of temporal frames was noted as early as the initial 2001 RFT textbook, yet decades have gone by with similar statements being issued concerning the minimal progression of work in this area. Prior to this research program, existing work on temporal relational responding had predominantly been restricted to neurotypical adults (Brassil et al., 2019; Hyland et al., 2012, 2014; McGreal et al., 2016; O'Hora et al., 2004, 2005, 2008) and the little work done with children had been relatively limited in scope (Kirsten & Stewart, 2022). The current research extends the literature base on temporal relations, particularly with respect to the acquisition and training of this repertoire in children. Specifically, this research on temporal relational responding extended empirical work to new demographics, provided initial data on potential developmental trends, designed a method for assessment of this repertoire, and developed an effective approach to training. Although this thesis certainly does not comprehensively fill the gaps identified in the above passages, it arguably provides a conceptual and empirical footing in which subsequent research can be built.

The current thesis also made a key contribution to the literature by extending empirical work on relational responding more generally. A core proposition in RFT is that relating is an operant that comes under contextual control. According to RFT, a generalized skill of relating is learned across a variety of opportunities, often occurring in natural language contexts. However, what is less clear, is when certain relational framing skills typically emerge in terms of age or relative to other frames. Some RFT work has begun to reveal insights in terms of general developmental trends with various relational repertoires (Kirsten & Stewart, 2022; McHugh et al., 2004; Mulhern et al., 2017). These types of findings are particularly useful for assisting in the guidance of creating programs designed to improve relational skills. Having data on when certain frames tend to emerge or in what type of sequence can help inform better age-appropriate learning targets for practitioners. The results from Study 1 in this thesis add to the literature in this area as it provides a data set on how children at different ages might respond on temporal relational tasks.

Along these lines, several studies have additionally shown that for individuals that are still acquiring certain relational skills, arranging MET testing and training conditions can lead to improvements (Barnes-Holmes, Barnes-Holmes, Smeets, et al., 2004; Belisle et al., 2016; Mulhern et al., 2018). Although MET has been shown to be effective for improving relational responses, no work had demonstrated this with temporal "before" and "after" relations. Studies 2 and 3 specifically showed that a MET approach can be effectively extended to training arbitrary temporal relations as well. Even though AARR is considered an overarching repertoire, various relational patterns can still be distinguished from another, such as by the way stimulus function transform based on the relational pattern. As such, it is important to continue to examine AARR across different relational patterns. Nonetheless, instances of relating across different frames should still show a degree of commonality if they are to be conceptualized under a generalized repertoire. The findings from Studies 2 and 3 add to the body of work suggesting that AARR is an operant that can be strengthened and brought under contextual control.

Although RFT primarily emphasizes the importance of AARR, many early relational operants are considered to have nonarbitrary counterparts which provide foundational building blocks to purely symbolic acts of relating (Berens & Hayes, 2007; Ming et al., 2018). To that end, investigating the acquisition of these nonarbitrary relational repertoires may be particularly important, especially in contexts where individuals have significant deficits in relational responding. Refining instructional procedures for nonarbitrary relational repertoires could thereby help fill in gaps in relational skills more effectively and efficiently. Study 4 contributed to the literature by providing an initial data set on training nonarbitrary “before” and “after” relations based on an RFT approach. The findings from Study 4 additionally supported the general finding from Studies 2 and 3 that MET is an effective intervention approach.

An interesting pattern that emerged from this research program was the contrasting performance with arbitrary “before” and “after” contextual cues. As discussed in Chapter 3 (Study 1), children across ages tended to respond comparably with both cues on nonarbitrary trials. However, with arbitrary trials, “after” cues were responded to with much less accuracy than “before” cues. As a reminder to the reader, this pertains to trials in which the relational statement included “before” or “after” (e.g., [red] B [blue] or [red] A [blue]) and not the contextual cue within the question asked (e.g., “Is red before/after blue?”). In Studies 2 and 3, a similar pattern was observed on arbitrary trials, and this only changed with the introduction of MET for all participants.

This finding appears to be somewhat consistent with existing RFT work as well as other psychological research on “before” and “after” comprehension. Existing RFT experimental research has reliably found that neurotypical adults with fully developed relational repertoires still respond slower on “after” trials compared to “before” (Brassil et al., 2019; Hyland et al., 2012; Hyland et al., 2014; McGreal et al., 2016). Although the research in this thesis did not include a response latency measure, there is a similarity in the sense that better performance was observed with responding to “before” statements compared to “after” statements in participants. Secondly, developmental and linguistic studies on “before” and “after” comprehension have typically found that children perform better when given a sentence describing a temporal sequence matches the actual temporal sequence compared to when the description is reversed (McCormack & Hanley, 2011; Trosborg, 1982). Interestingly, this means that it is not simply that children understand “before” better than “after,” as either cue could be included in either matching sentences (“A is before B;” “After A, is B”) or reversed sentences (“Before A, is B;” “B is after A”). The correspondence between the description and actual event sequence appears to be a larger factor in terms of performance. This parallels data from the current thesis. If performance was simply a function of participants not understanding “after,” then the data would reveal errors whenever an “after” question was asked. However, this was not the case as the discrepancy in accuracy was observed relative to the type of relational statement presented, which is analogous to whether a description matches a temporal sequence or is reversed.

This observed difference between responding to “before” and “after” relational statements can be examined along the dimensions within the HDML framework (Barnes-Holmes et al., 2020). These dimensions include: coherence (How consistent is the relational response with one’s learning history?), complexity (How detailed is the relational response?), derivation (How well-practiced is the relational response?) and flexibility (How readily does the relational response change as required in a new context?). A particular relational response may be analyzed along a continuum (e.g., high to low) for each of these dimensions.

The dimension of coherence is relevant in two ways. On one hand, as discussed in Chapter 5 (Study 3), “before” relational statements are more coherent than “after” as the sequence described in the relational statement corresponds with an actual nonarbitrary temporal relation (observing or hearing the stimuli in a particular order). Secondly, responding to “before” relational statements is more coherent with a likely learning history for sequencing events left-to-right. Although access to the participants’ specific learning histories is not possible, this point appears relevant given the ages of participants. For example, Tillman et al. (2022) showed that directional preference for ordering temporal events begins to emerge around 5 years, coinciding with a considerable increase in exemplars for ordering in this direction (e.g., reading). As such, the socioverbal community tends to reinforce relating events in the particular way, which is more coherent with “before” relational statements than “after.”

The response differences may also be examined in terms of complexity. In this thesis, complexity was manipulated by presenting relations between 2 relata (ME trials) and subsequently increasing the number of relata to 3 (CE trials)[10]. Relational networks involving 3 relata would be considered higher in complexity than those with 2 relata. In Study 1 and baseline of Studies 2 and 3, performances of participants on arbitrary “before” trials were typically higher than arbitrary “after” trials at both levels of complexity. In a few instances however, response patterns changed when complexity increased. During baseline of Study 3 for example, P1 responded more accurately to ME “before” trials than ME “after” trials (average of 81% and 31% correct, respectively); whereas on CE trials, P1 responded “no” to all CE questions presented (hence demonstrating chance level

[10] Relational complexity can be defined along multiple dimensions, such as the number of relata, frames, or contextual cues in a relational network (Barnes-Holmes et al., 2020).

performance). As such, manipulations in complexity may in some instances be relevant to response patterns between contextual cues.

The HDML dimension of derivation may also be relevant, though empirical testing is warranted. As discussed in Study 1 (Chapter 3), one possible partial explanation for more accurate responding toward “before” trials compared to “after” is that the degree of practice with each cue in the natural environment might be a factor. Relational responses that are well-practiced would be considered lower in derivation than be responses with less practice. Two questions for empirical testing relative to derivation include whether children receive more exposure to “before” relations than “after” relations, and whether children receive more practice deriving “after” relations when given a “before” statement than the reverse. Whether or not children do in fact receive more practice with temporal relations like this within in their socioverbal environments requires empirical investigation.

Lastly, flexibility of the relational response was invoked by introducing MET. In all participants, relational responses on “after” trials changed when the reinforcing context changed. The degree to which a participant’s repertoire was flexible was more idiosyncratic, however. In Study 2 for instance, one participant found it more difficult to respond accurately on trial blocks when relational statements were mixed with both "before" and "after" cues compared to when they were presented in isolation (i.e., "before" statements only, and then "after" only). The relational responding in this example is lower in flexibility compared to a response pattern that can more readily shift between changing relational conditions.

There are both theoretical and applied implications of this finding on contextual control. Other applied RFT work has often not reported in detail on performance differences between contextual cues when a particular frame entails more than one relation (e.g., comparison, hierarchical). The data from the current thesis highlighted that this was an especially relevant consideration relevant to contextual control with temporal relations, and simply reporting on the overall accuracy with both cues would have provided an incomplete learning picture. At present, it is not clear whether this finding is similar with other frames involving multiple contextual cues. Comparing performance across contextual cues (e.g., baseline to intervention changes, rates of acquisition) with other frames could offer a more complete picture in terms of the acquisition of AARR repertoires in childhood. The applied implication of this result also suggests that practitioners working with individuals with emerging relational skills should consider collecting data on tests for derivation across various presentations of relational networks and question types. By doing so, decision making in terms of intervention adjustments could be enhanced (e.g., providing booster sessions or trial blocks with certain trial types).

Another interesting theoretical consideration is that a nonarbitrary temporal relation is technically always in effect regardless of the type of relational network presented (whether a temporal frame, or otherwise). Organisms experience events sequentially in time and this is true for verbal stimuli as well. In other words, when reading a relational network or hearing it spoken aloud, a person orients to these stimuli in sequence. Future work might consider to what degree this dynamic interacts with relational responding more generally.

Approaching responding to “before” and “after” from an operant perspective also offers application to the broader literature base. As discussed in Chapter 1, different psychological perspectives on behavior may pursue slightly different scientific goals through different means. These philosophical world views need not be in competition, but rather, can each offer a unique insight into a particular phenomenon. Existing work, primarily from cognitive developmental and linguistic approaches, has explored the comprehension of “before” and “after” in terms of age-related performance (Busby Grant & Suddendorf, 2011), arranging sentence variations (Clark, 1971), and connections to neural correlates (Ye et al., 2012) or cognitive processes (Blything et al., 2015). This work has helped inform models that align more closely with mechanistic or organicist leanings. However, one gap in the literature is that these studies have mostly been observational or descriptive, limiting what can be understood in terms of the acquisition of these skills. The current research introduced an alternative perspective (contextualistic) on this phenomenon (temporal relations) to the broader literature base which offers an advantage relative to the is research gap. Data from this thesis provided a specific methodology for the prediction and influence of an operant behavior involved in the comprehension of “before” and after.” Further, this behavioral approach provides insight into distinguishing between different sources of stimulus control over “before/after” responding, which previous research has not explored. Responses may be contextually controlled by a nonarbitrary temporal relation, a solely arbitrary contextual cue, or a combination. Just as these cited findings helped inform this research program, so too can this data inform future work rooted in other philosophical assumptions. Cooperation and collaboration around a particular phenomenon rather than working in silos will hopefully lead to better research, leading to better technologies, leading to a more meaningful impact on consumers. Indeed, there are many interesting points of intersection between branches of psychology surrounding relational reasoning or learning (McLoughlin, Tyndall, & Pereira, 2020). Continued integration in this area is a promising direction.

A final major contribution from the current work is that it helped provide conceptual basis for approaching a range of other time-related skills to be approached behaviorally. Although the empirical work detailed in Chapters 3-6 focused specifically on temporal relational skills with “before” and “after” cues, there are other adjacent time-related repertoires. Friedman (2011, p. 398) described that time involves, “recurrent sequences of events, natural and conventional time patterns, invariant causal sequences, logical relations between succession and duration, the past-present-future distinction, and many others.” Chapter 2 specifically highlighted the key skills of timing, clock and calendar acquisition, self-control, planning, and time management. From an RFT view, various other relational skills may be relevant to these skill sets (e.g., frames of coordination with duration units; comparison relations with immediate and delayed contingencies; relational networks involved in planning and time management). Even with temporal event sequencing, there is room for work beyond simple “before” and “after” comprehension (e.g., deictic relations with past and future sequences, causal relations, etc.). In conjunction with the literature reviewed across these domains, an RFT interpretation was presented that could allow for the development of methods to support research in these areas.

Limitation and Future Research Directions

Despite the contributions offered through the current research program, several limitations were evident which should be addressed in continued work. This section provides an overview of these limitations, suggested ways to address them, as well as other potential areas of empirical investigation inspired by this work.

One limitation of this research is that the connection between temporal relational responding and other repertoires was not examined. RFT proposes that AARR is the key operant relevant to language and cognition (Hughes & Barnes-Holmes, 2016). Accordingly, language-based skills or cognitive skills might be specifically examined in relation to instances of AARR. Future work could utilize the temporal relational responding assessment used in Study 1 and compare performance relative to standardize measures of language or cognitive skills (e.g., Peabody Picture Vocabulary Test, Stanford-Binet Intelligence Scales, Bracken Basic Concept Scale) in a larger sample. Further, future work could examine whether training in temporal relational responding aids in performance on any of these measures. Alternatively, research could compare temporal relational responding performance with other behavioral repertoires not necessarily measured by standardized measures. In Chapter 2, a range of temporal skill sets were specifically identified. Future work could compare how acquisition of temporal relational responding intersects with performance on tasks designed to measure skills like planning (e.g., route-planning tasks) or self-control (e.g., delay of gratification tasks).

A second area for continued work is to address the relatively limited scope with responses and stimuli used in the testing and training protocols. In this thesis, all the arbitrary relations were presented using an adapted REP format. This particular method provides an advantage in terms efficiency (Kirsten et al., 2022a). It is unclear however, if similar performance patterns would have been obtained using alternative methods, such as a match-to-sample (MTS) arrangement. Future work could investigate temporal frames in this context to see what kind of results an MTS approach provides. Along these lines, future work might consider using different spatial arrangements for presenting relational networks, include other stimuli (e.g., either culturally relevant or more abstract stimuli), present stimuli across different sense modalities, and train across additional contextual cues (e.g., earlier/later, first/then). It is also recommended that future work include broadening the types of responses included within a MET protocol, such as tacting the relation, selection-based responses, orienting responses, other stimulus functions, and/or higher levels of relational responding in the HDML.

Future work might also look at the importance of nonarbitrary relations. In this thesis, Study 4 did not explicitly extend training beyond contextually controlled responding to nonarbitrary temporal relations. Subsequent research should examine whether such acquisition supports learning arbitrary temporal relations. For example, Berens and Hayes (2007) found that including nonarbitrary pre-trials as an intervention component supported acquisition of arbitrary comparison relating. Similar work can be extended to temporal relations. Moreover, the current protocol was limited insofar as the timescale that was used (e.g., 1s intervals). Subsequent research should incorporate the testing and training of nonarbitrary relations with longer (or varied) durations. Additionally, future work could examine the utility of using nonarbitrary relations to support the acquisition of other time skills. For example, duration units might be taught by using visual nonarbitrary comparison relations (e.g., 1 hour vs 1 minute comparison using visual bars, etc.).

Another limitation in the current work is that a social validity measure was not included for the trainings. As the training studies were preliminary investigations in terms of developing an intervention, priority was placed on first evaluating its efficacy. Future iterations of this intervention should additionally include direct consumer feedback. Participants could offer feedback in terms of their experience participating in the training and offer ideas for improvement. In addition to measuring social validity with children or their families, this could be applied to behavioral practitioners as well. For example, future work could instead have clinicians implement the RFT based protocol, and they could share their experience, perspective, or challenges implementing it.

The issue of social validity is perhaps a more widespread area of need within applied RFT work, let alone behavior analysis more generally. Given that social significance is a fundamental principal within ABA (Baer et al., 1968), this is an area that should take priority in future applied RFT work. For instance, this research line could be adapted into more naturalistic settings (e.g., play scenarios) or embed more functional response sequences (e.g., life skills) to increase social validity. One empirical example to build on utilized equivalence based instruction (EBI) to teach a generalized grocery store shopping sequence (Taylor & O’Reilly, 2000). One dyad was taught the shopping sequence in vivo across multiple grocery stores, while participants in the EBI dyad practiced the skill in one store but completed EBI with pictures of different stores. The EBI dyad demonstrated similar generalization performance compared to the multiple stores dyad when assessed in a novel store. This intervention only used equivalence relations, however, any behavior chain in which the order of actions is important (e.g., steps for cooking, etc.) could also incorporate training temporal relations.

A potential roadblock encountered by clinicians when implementing interventions targeting derived relations in practice is the complex nature of creating programs. Protocols often include a high number of discrete trials, systematic rotation of stimuli, ensuring appropriate testing conditions for derived relations, and navigating potentially less familiar terminology (Marano-Frezza et al., 2022). These are not insurmountable challenges to a clinician; however, it may still require a higher response effort on their part compared to more familiar ABA programming. Considering the emerging evidence that relation training may enhance outcomes in ABA intervention (Dixon et al., 2023) however, increased attention in this area is appropriate.

One avenue that might help address both the concerns of social validity and clinician response effort or error, is through investing in creating technology-based programs that incorporate RFT. Digital platforms offer the benefit of automating certain tasks, which could assist with program design (e.g., selecting and arranging stimuli, data collection on trials, etc.). Additionally, some language learning software platforms infuse artificial intelligence (AI) into their design, which further reduces the burden on the instructor and could potentially enhance learning opportunities for consumers. For example, platforms such as Duolingo or ELSA embed AI, which helps identify errors made, provide feedback, adapt trial blocks, and personalize lessons to fit the needs of the learner. It is reasonable that that such an approach can fit within the scope of relational training. Although some designs currently exist such as SMART Training (Cassidy et al., 2016) or the T-IRAP (Murphy et al., 2019), there is room for more consumer-friendly designs along with integrating present technological advances. This could reduce a barrier of needing to "know" RFT well on the part of the clinician, while also broadening the scope for implementation via caregivers, teachers, or even child-directed learning.

Conclusion

This thesis contributes to the limited research on temporal relational responding by extending empirical investigation to new demographics, and by designing testing and training procedures for improving responding. Findings from this thesis provide evidence that an RFT-based assessment procedure can be used to determine temporal relational responding skill level, which in turn can help guide intervention. This work extends existing RFT research that MET training can effectively improve relational responding performance in both neurotypical and neurodiverse individuals at multiple levels (i.e., arbitrary and nonarbitrary relations). This thesis also provides a conceptual analysis for other potential areas of RFT application within psychological research on time-related skill sets. The findings from this thesis are preliminary, however. More research is needed to replicate the results, refine the testing and training procedures, and show relevancy of these relational responses to other adaptive skill sets. Given the importance of responding to temporal features of the environment and the advantages that a verbal experience of time offers, continued work in this area is warranted.

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Appendices

Appendix A: Temporal Relations Assessment Trial List

Nonarbitrary Trial Types

Observed Sequence	Question	Correct Response
Bike then fish	Was bike before fish?	Yes
Fish then shoe	Was shoe before fish?	No
Shoe then cookie	Was shoe after cookie?	No
Cookie then plane	Was plane after cookie?	Yes
Plane then cat	Was plane before cat?	Yes
Cat then ball	Was ball before cat?	No
Ball then apple	Was ball after apple?	No
Apple then bike	Was bike after apple?	Yes
Bike then shoe then cat	Was bike before cat?	Yes
Shoe then cat then apple	Was apple before shoe?	No
Cat then apple then plane	Was cat after plane?	No
Apple then plane then ball	Was ball after apple?	Yes
Plane then ball then fish	Was plane before fish?	Yes
Ball then fish then cookie	Was cookie before ball?	No
Fish then cookie then bike	Was fish after bike?	No
Cookie then bike then shoe	Was shoe after cookie?	Yes

Arbitrary Trial Types

	Mutual Entailment	
Relational Statement	Question	Correct Response
Red before blue	Is red before blue?	Yes
Blue before yellow	Is yellow before blue?	No
Yellow before green	Is yellow after green?	No
Green before red	Is red after green?	Yes
Red after blue	Is red before blue?	No
Blue after yellow	Is yellow before blue?	Yes
Yellow after green	Is yellow after green?	Yes
Green after red	Is red after green?	No
Blue before red	Is red before blue?	No
Yellow before blue	Is yellow before blue?	Yes
Green before yellow	Is yellow after green?	Yes
Red before green	Is red after green?	No
Blue after red	Is red before blue?	Yes
Yellow after blue	Is yellow before blue?	No
Green after yellow	Is yellow after green?	No
Red after green	Is red after green?	Yes
	Combinatorial Entailment	
Relational Statement	Question	Correct Response
Red before blue, blue before yellow	Is red before yellow?	Yes
Blue before yellow, yellow before green	Is green before blue?	No
Yellow before green, green before red	Is yellow after red?	No
Green before red, red before blue	Is blue after green?	Yes
Red after blue, blue after yellow	Is red before yellow?	No
Blue after yellow, yellow after green	Is green before blue?	Yes
Yellow after green, green after red	Is yellow after red?	Yes
Green after red, red after blue	Is blue after green?	No
Yellow before blue, blue before red	Is red before yellow?	No
Green before yellow, yellow before blue	Is green before blue?	Yes
Red before green, green before yellow	Is yellow after red?	Yes
Blue before red, red before green	Is blue after green?	No
Yellow after blue, blue after red	Is red before yellow?	Yes
Green after yellow, yellow after blue	Is green before blue?	No
Red after green, green after yellow	Is yellow after red?	No
Blue after red, red after green	Is blue after green?	Yes
	Transformation of Function Trial Types	
Assigned function (for all ToF trials)	Relational statement	Correct response
Red → clap	Red before blue	Claps then raises hand
Blue → raise hand	Blue before yellow	Raises hand then touches nose
Yellow → touch nose	Yellow before green	Touches nose then waves
Green → wave hand	Green before red	Waves then claps
	Red after blue	Raises hand then claps
	Blue after yellow	Touches nose then raises hand
	Yellow after green	Waves hand then touches nose
	Green after red	Claps then waves
	Red before blue, blue before yellow	Claps then raises hand then waves hand
	Blue before yellow, yellow before green	Raises hand then touches nose then waves
	Yellow before green, green before red	Touches nose then waves then claps
	Green before red, red before blue	Waves then claps then raises hand
	Red after blue, blue after yellow	Touches nose then raises hand, then claps
	Blue after yellow, yellow after green	Waves then touches nose then raises hand
	Yellow after green, green after red	Claps then waves then touches nose

Appendix B: Training Protocol

Arbitrary Trials: Mutual Entailment (Yes/No)

Target behavior: When given a context of a relation between 2 stimuli, the participant will derive the mutually entailed relation evidenced by a "yes" vocal response when the presented question corresponds with the relation and a "no" vocal response when the presented question does not correspond with the relation.

- Correct responses include: If given the context A is before B, and asked, "Is A before B?" the participant will say, "yes." If given the context B is after A, and asked, "Is B after A?" the participant will say, "no."
- Incorrect responses include: Saying "no" when the correct answer is "yes" or saying "yes" when the correct answer is "no", saying both "yes" and "no" in succession, or providing no response after 10s.

Materials: pictures of mastered stimuli (e.g., colors, shapes, and common items).

Train Block (stimulus set 1: same set from assessment)

1. Implementation Steps:
   a. Present 2 sample stimuli with a contextual cue that indicates the directly trained relation (e.g., red B blue).
   b. Present one of the four trial types (i.e., "Is A before B?" "Is B before A?" "Is A after B?" "Is B after A?")
   c. If participant emits the correct response, immediately provide specific verbal praise and provide token.
   d. If participant emits an incorrect response, provide verbal feedback and instruct the participant to try again.
      i. If participant responds correctly after receiving verbal feedback, provide specific verbal praise.
      ii. If error persists, repeat instruction while simultaneously modeling the correct response. Do not provide verbal praise and move on to next trial.
   e. Repeat sequence with the other 3 types of question formats.
2. Reinforcement plan: use tokens, back-up reinforcers, and specific verbal praise
   a. Provide token for each independent response. Once all tokens have been earned, they can be exchanged for a back-up reinforcer at the following time: _______
   b. Provide specific social praise for each independent response and for correct responses following verbal feedback.
   c. Session reward can be earned by beating the number of correct responses from the previous session. (Gilroy 2015; Mulhern, 2018)
3. Data collection:
   a. Score (+) for each trial in which the question was answered correctly and independently.
   b. Score (-) for each trial in which the question required a prompt to be answered correctly.
4. Mastery criteria: ≥ 85% accuracy across 2 consecutive sessions.
   a. Once the participant reaches mastery criteria with the training set, proceed to next to test for mutual entailment with novel stimulus set

Test Block (novel stimulus set)

1. Complete a test block with a novel stimulus set once mastery is obtained with the trained stimulus set.
2. All test trials are identical to training trials with exception of consequences for correct responses, incorrect responses, and the use of a novel stimulus set
   a. For correct responses, <u>do not</u> provide verbal raise or tokens
   b. For incorrect responses, <u>do not</u> provide prompting/error-correction
3. Mastery criteria: ≥ 85% for one session.
   a. If participant fails to meet mastery criteria on the test set, immediately begin MET with this stimulus set.
   b. Once training criteria is reached with the current stimulus set, re-test the participant on another novel set.
      i. If the participant fails this test, repeat this training sequence until sequence until the test is passed.
   c. Once the mastery criteria for the test block is reached, proceed to next phase of intervention.

Maintenance and Generalization: Conduct maintenance probes at 3 weeks and 6 weeks post-intervention.

1. All maintenance checks will be conducted with same stimuli that were used in training blocks.
2. Stimuli used in test blocks will be used for generalization probes.

Arbitrary Combinatorial Entailment (Yes/No)

Target behavior: When given a context of a relation between 2 stimuli, the participant will derive the mutually entailed relation evidenced by a "yes" vocal response when the presented question corresponds with the relation and a "no" vocal response when the presented question does not correspond with the relation.

- Correct responses include: If given the context A is before B, and asked, "Is A before B?" the participant will say, "yes." If given the context B is after A, and asked, "Is B after A?" the participant will say, "no."
- Incorrect responses include: Saying "no" when the correct answer is "yes" or saying "yes" when the correct answer is "no", saying both "yes" and "no" in succession, or providing no response after 10s.

Materials: pictures of colors, shapes, and common items.

Train Block (stimulus set 1: same set from assessment)

1. Implementation Steps:
   a. Present 2 sample stimuli with a contextual cue that indicates the directly trained relation (e.g., red B blue).
   b. Present one of the four trial types (i.e., "Is A before B?" "Is B before A?" "Is A after B?" "Is B after A?")
   c. If participant emits the correct response, immediately provide specific verbal praise and provide token.
   d. If participant emits an incorrect response, provide verbal feedback and instruct the participant to try again.
      i. If participant responds correctly after receiving verbal feedback, provide specific verbal praise.
      ii. If error persists, repeat instruction while simultaneously modeling the correct response. Do not provide verbal praise and move on to next trial.
   e. Repeat sequence with the other 3 types of question formats.
2. Reinforcement plan: use tokens, back-up reinforcers, and specific verbal praise
   a. Provide token for each independent response. Once all tokens have been earned, they can be exchanged for a back-up reinforcer at the following time: ________
   b. Provide specific social praise for each independent response and for correct responses following verbal feedback.
   c. Session reward can be earned by beating the number of correct responses from the previous session. (Gilroy 2015; Mulhern, 2018)
3. Data collection:
   a. Score (+) for each trial in which the question was answered correctly and independently.
   b. Score (-) for each trial in which the question required a prompt to be answered correctly.
4. Mastery criteria: ≥ 85% accuracy across 2 consecutive sessions.
   a. Once the participant reaches mastery criteria with the training set, proceed to next to test for mutual entailment with novel stimulus set

Test Block (novel stimulus set)

1. Complete a test block with a novel stimulus set once mastery is obtained with the trained stimulus set.
2. All test trials are identical to training trials with exception of consequences for correct responses, incorrect responses, and the use of a novel stimulus set
   a. For correct responses, <u>do not</u> provide verbal raise or tokens
   b. For incorrect responses, <u>do not</u> provide prompting/error-correction
3. Mastery criteria: ≥ 85% for one session.
   a. If participant fails to meet mastery criteria on the test set, immediately begin MET with this stimulus set.
   b. Once training criteria is reached with the current stimulus set, re-test the participant on another novel set.
      i. If the participant fails this test, repeat this training sequence until sequence until the test is passed.
   c. Once the mastery criteria for the test block is reached, proceed to next phase of intervention.

Maintenance and Generalization: Conduct maintenance probes at 3 weeks and 6 weeks post-intervention.

1. All maintenance checks will be conducted with same stimuli that were used in training blocks.
2. Stimuli used in test blocks will be used for generalization probes.

Transformation of Function—Mutual Entailment

Target behavior: The participant will do the sequence of motor actions in the correct order as indicated by the relational statement.

- Correct responses include: given an image of "red *before* blue" and trained that red = clap, and blue = raise hand; the participant first claps, and then raises their hand. Given an image of red *after* blue and trained red = clap and blue = raise hand; the participant first raises their hand, and then claps.
- Incorrect responses include: acting out the target actions in the incorrect order, acting out the actions simultaneously, or acting out other actions.

Materials: pictures of colors, shapes, and common items; visual of color-motor action correspondence.

Pre-training (complete at the beginning of each training session):
1. Present stimulus from the current set.
2. Vocally state and model the motor action that corresponds with the stimulus.
3. Allow student opportunity to imitate the action and repeat with all stimuli in the set.
4. Re-present stimuli in random order to test for accuracy.
   a. If participant accurately demonstrates all actions without prompting, proceed to training phase.
   b. If less than 100%, repeat steps 1-4 until accurate with all stimuli in the set.

Training:
1. Implementation Steps:
   a. Present 2 sample stimuli with a contextual cue that indicates the directly trained relation (e.g., red B blue).
   b. Also present the color-motor actions visual for learner.
   c. Next, read the relation out-loud (e.g. "e.g., red is before blue.")
   d. Deliver instruction for learner to perform the actions in the correct order (e.g., "Do these actions in order).
   e. If participant emits the correct response, immediately provide specific verbal praise and provide token.
   f. If participant emits an incorrect response, provide verbal feedback and instruct the participant to try again.
      i. If participant responds correctly after receiving verbal feedback, provide specific verbal praise.
      ii. If error persists, repeat instruction while simultaneously modeling the correct response. Do not provide verbal praise and move on to next trial.
   g. Repeat sequence with the remaining trials in the trial block.
2. Reinforcement plan: use tokens, back-up reinforcers, and specific verbal praise
   a. Provide token for each independent response. Once all tokens have been earned, they can be exchanged for a back-up reinforcer at the following time: ____
   b. Provide specific social praise for each independent response and for correct responses following verbal feedback.
   c. Session reward can be earned by beating the number of correct responses from the previous session. (Gilroy 2015; Mulhern, 2018)
3. Data collection:
   a. Score (+) for each trial in which both actions were acted out in the correct order.
   b. Score (-) for each trial in which an incorrect response was made (see above).
4. Mastery criteria: ≥ 85% accuracy across 2 consecutive sessions.
   a. Once the participant reaches mastery criteria with the training set, proceed to next to test for transformation of function via mutual entailment with novel stimulus set.

Testing:
1. Complete a test block with a novel stimulus set once mastery is obtained with the trained stimulus set.
2. All test trials are identical to training trials with exception of consequences for correct responses, incorrect responses, and the use of a novel stimulus set.
   a. For correct responses, <u>do not</u> provide verbal raise or tokens
   b. For incorrect responses, <u>do not</u> provide prompting/error-correction
3. Mastery criteria: ≥ 85% for one session.
   a. If participant fails to meet mastery criteria on the test set, immediately begin MET with this stimulus set.
   b. Once training criteria is reached with the current stimulus set, re-test the participant on another novel set.
      i. If the participant fails this test, repeat this training sequence until sequence until the test is passed.
   c. Once the mastery criteria for the test block is reached, proceed to next phase of intervention.

Maintenance and Generalization: Conduct maintenance probes at 3 weeks and 6 weeks post-intervention.
1. All maintenance checks will be conducted with same stimuli that were used in training blocks.
2. Stimuli used in test blocks will be used for generalization probes.

Transformation of Function—Combinatorial Entailment

Target behavior: The participant will do the sequence of motor actions in the correct order as indicated by the relational statement.

- Correct responses include: given an image of "red *before* blue *before* yellow" and trained that red = clap, blue = raise hand, and yellow = tap table; the participant first claps, then raises their hand, then taps the table. Given an image of red *after* blue *after* yellow and trained red = clap, blue = raise hand, and yellow = tap table; the participant first taps the table, then raises their hand, and then claps.
- Incorrect responses include acting out the target actions in the incorrect order, acting out the actions simultaneously, or acting out other actions.

Materials: pictures of colors, shapes, and common items; visual of color-motor action correspondence.

Pre-training (complete at the beginning of each training session):

1. Present stimulus from the current set.
2. Vocally state and model the motor action that corresponds with the stimulus.
3. Allow student opportunity to imitate the action and repeat with all stimuli in the set.
4. Re-present stimuli in random order to test for accuracy.
    a. If participant accurately demonstrates all actions without prompting, proceed to training phase.
    b. If less than 100%, repeat steps 1-4 until accurate with all stimuli in the set.

Training:

1. Implementation Steps:
    a. Present 2 sample stimuli with a contextual cue that indicates the directly trained relation (e.g., red B blue).
    b. Also present the color-motor actions visual for learner.
    c. Next, read the relation out-loud (e.g. "e.g., red is before blue.")
    d. Deliver instruction for learner to perform the actions in the correct order (e.g., "Do these actions in order).
    e. If participant emits the correct response, immediately provide specific verbal praise and provide token.
    f. If participant emits an incorrect response, provide verbal feedback and instruct the participant to try again.
        i. If participant responds correctly after receiving verbal feedback, provide specific verbal praise.
        ii. If error persists, repeat instruction while simultaneously modeling the correct response. Do not provide verbal praise and move on to next trial.
    g. Repeat sequence with the remaining trials in the trial block.
2. Reinforcement plan: use tokens, back-up reinforcers, and specific verbal praise
    a. Provide token for each independent response. Once all tokens have been earned, they can be exchanged for a back-up reinforcer at the following time: ____
    b. Provide specific social praise for each independent response and for correct responses following verbal feedback.
    c. Session reward can be earned by beating the number of correct responses from the previous session. (Gilroy 2015; Mulhern, 2018)
3. Data collection:
    a. Score (+) for each trial in which all three actions were acted out in the correct order.
    b. Score (-) for each trial in which an incorrect response was made (see above).
4. Mastery criteria: ≥ 85% accuracy across 2 consecutive sessions.
    a. Once the participant reaches mastery criteria with the training set, proceed to next to test for transformation of function via mutual entailment with novel stimulus set.

Testing:

1. Complete a test block with a novel stimulus set once mastery is obtained with the trained stimulus set.
2. All test trials are identical to training trials with exception of consequences for correct responses, incorrect responses, and the use of a novel stimulus set.
    a. For correct responses, <u>do not</u> provide verbal raise or tokens
    b. For incorrect responses, <u>do not</u> provide prompting/error-correction
3. Mastery criteria: ≥ 85% for one session.
    a. If participant fails to meet mastery criteria on the test set, immediately begin MET with this stimulus set.
    b. Once training criteria is reached with the current stimulus set, re-test the participant on another novel set.
        i. If the participant fails this test, repeat this training sequence until sequence until the test is passed.
    c. Once the mastery criteria for the test block is reached, proceed to next phase of intervention.

Maintenance and Generalization: Conduct maintenance probes at 3 weeks and 6 weeks post-intervention.

1. All maintenance checks will be conducted with same stimuli that were used in training blocks.
2. Stimuli used in test blocks will be used for generalization probes.

Appendix C: Example Data Sheets

Learner ID: ________ **Arbitrary Mutual Entailment** Date: ________
Initials: ________

Phase	**Stimulus Set** Set #: ____		Stimulus	Stimulus	**Notes**
Baseline ____		Stimulus	A1 red	A2 blue	
Train ____	1	red	B1 blue	B2 yellow	
Test ____	2	blue	A3 yellow	A4 green	
Maint. ____	3	yellow	B3 green	B4 red	
Gen. ____	4	green			

1. Present trials in random order.
2. For each trial, present the instruction listed in the corresponding row. Follow protocol according to current phase of data collection.
3. On the first trial of each trial type, record the participant's response.
4. For first trial probes on trial types answered incorrectly, run additional training trials.

#	Trial Type	Stimulus Presentation	Instruction	Answer	1st Trial Probe	Additional Training Trials
1	A1 b B1	red b blue	red before blue?	***Yes***		
2	A1 a B1	red a blue	red before blue?	***No***		
3	A2 b B2	blue b yellow	yellow before blue?	***No***		
4	A2 a B2	blue a yellow	yellow before blue?	***Yes***		
5	A3 b B3	yellow b green	yellow after green?	***No***		
6	A3 a B3	yellow a green	yellow after green?	***Yes***		
7	A4 b B4	green b red	red after green?	***Yes***		
8	A4 a B4	green a red	red after green?	***No***		
				First trial probes correct/8	**/8**	
				% first trial probes correct	**%**	

Appendix C

Learner ID: ________ **Arbitrary Transformation of Function - Mutual Entailment** Date: ________
Initials: ________

Phase	**Stimulus Set** Set #: ____			Stimulus	Action		Stimulus	Action	**Notes**
		Stimulus	Motor Action	A1 red	clap	A2 blue	raise hand		
Baseline ____				B1 blue	raise hand	B2 yellow	tap table		
Train ____	1	red	clap						
Test ____	2	blue	raise hand	A3 yellow	tap table	A4 green	wave		
Maint. ____	3	yellow	tap table	B3 green	wave	B4 red	clap		
Gen. ____	4	green	wave						

1. Present trials in random order.
2. For each trial, present the instruction, "Do these in order." Follow protocol according to current phase of data collection.
3. On the first trial of each trial type, record (+) if independent and (—) if prompt required.
4. For first trial probes on trial types answered incorrectly, run additional training trials.

#	**Trial Type**	**Stimulus Presentation**	**Answer**	**1st Trial Probe**	**Additional Training Trials**
1	A1 b B1	red b blue	clap—raise hand		
2	A1 a B1	red a blue	raise hand—clap		
3	A2 b B2	blue b yellow	raise hand—tap table		
4	A2 a B2	blue a yellow	tap table—raise hand		
5	A3 b B3	yellow b green	tap table—wave		
6	A3 a B3	yellow a green	wave—tap table		
7	A4 b B4	green b red	wave—clap		
8	A4 b B4	green a red	clap—wave		
			First trial probes correct/8	**/8**	
			% first trial probes correct	**%**	

Learner ID: ________

Arbitrary Combinatorial Entailment

Date: ________
Initials: ________

Phase	**Stimulus Set** Set #: ____		Stimulus		Stimulus		**Notes**
		Stimulus	A1	red	A2	blue	
Baseline ____			B1	blue	B2	yellow	
Train ____	1	red	C1	yellow	C2	green	
Test ____	2	blue	A3	yellow	A4	green	
Maint. ____	3	yellow	B3	green	B4	red	
Gen. ____	4	green	C3	red	C4	blue	

1. Present trials in random order.
2. For each trial, present the instruction kisted in the corresponding row. Follow protocol according to current phase of data collection.
3. On the first trial of each trial type, record the participant's response.
4. For first trial probes on trial types answered incorrectly, run additional training trials.

#	**Trial Type**	**Stimulus Presentation**	**Instruction**	**Answer**	**1st Trial Probe**	**Additional Training Trials**
1	A1 b B1 b C1	red b blue b yellow	red before yellow?	***Yes***		
2	A1 a B1 a C1	red a blue a yellow	red before yellow?	***No***		
3	A2 b B2 b C2	blue b yellow b green	green before blue?	***No***		
4	A2 a B2 a C2	blue a yellow a green	green before blue?	***Yes***		
5	A3 b B3 b C3	yellow b green b red	yellow after red?	***No***		
6	A3 a B3 a C3	yellow a green a red	yellow after red?	***Yes***		
7	A4 b B4 b C4	green b red b blue	blue after green?	***Yes***		
8	A4 a B4 a C4	green a red a blue	blue after green?	***No***		
				First trial probes correct/8	**/8**	
				% first trial probes correct	**%**	

Appendix C

Learner ID: ________ **Arbitrary Transformation of Function - Combinatorial Entailment** Date: ________ Initials: ________

Phase	**Stimulus Set** Set #: ____				Stimulus	Action		Stimulus	Action	**Notes**
		Stimulus	Motor Action	A1	red	clap	A2	blue	raise hand	
Baseline ____				B1	blue	raise hand	B2	yellow	tap table	
Train ____	1	red	clap	C1	yellow	tap table	C2	green	wave	
Test ____	2	blue	raise hand	A3	yellow	tap table	A4	green	wave	
Maint. ____	3	yellow	tap table	B3	green	wave	B4	red	clap	
Gen. ____	4	green	wave	C3	red	clap	C4	blue	raise hand	

1. Present trials in random order.
2. For each trial, present the instruction, "Do these in order." Follow protocol according to current phase of data collection.
3. On the first trial of each trial type, record (+) if independent and (—) if prompt required.
4. For first trial probes on trial types answered incorrectly, run additional training trials.

#	**Trial Type**	**Stimulus Presentation**	**Answer**	**1st Trial Probe**	**Additional Training Trials**
1	A1 b B1 b C1	red b blue b yellow	clap—raise hand—tap table		
2	A1 a B1 a C1	red a blue a yellow	tap table—raise hand—clap		
3	A2 b B2 b C2	blue b yellow b green	raise hand—tap table—wave		
4	A2 a B2 a C2	blue a yellow a green	wave—tap table—raise hand		
5	A3 b B3 b C3	yellow b green b red	tap table—wave—clap		
6	A3 a B3 a C3	yellow a green a red	clap—wave—tap table		
7	A4 b B4 b C4	green b red b blue	wave—clap—raise hand		
8	A4 a B4 a C4	green a red a blue	raise hand—clap—wave		
			First trial probes correct/8	**/8**	
			% first trial probes correct	**%**	