

Applying Complex Dynamic Systems Theory to Identify Dynamic Properties of Plurilingual Repertoires

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Language repertoires have been traditionally construed as a set of chronologically determined compartments (first language, second language, etc.), a scheme which upholds several validity and ethical issues when operationalized in research and education (Ortega, 2019). Complex dynamic systems theory (also complexity theory, here CDST) has been hailed as one solution moving forward, but its applicability to plurilingual settings requires further testing. This exploratory study contributes by examining whether inherent properties of complex dynamic systems manifest in the perceptions that plurilinguals have as their language systems change over time. Using retrodictive qualitative modelling (Dörnyei, 2014), this study discerned the developmental trajectory of changing language systems by working backwards through data collected during an observation window. Over a 3-month period, three plurilingual individuals assessed their language systems through weekly surveys and participated in open-ended interviews. A three-stage phenomenological analysis evaluated the data against CDST's theoretical prism to identify five CDST properties (attractor states, phase shifts, co-adaptation, self-organization, and emergence) in the participants' perceptions of their changing repertoires. Results indicate that plurilingual repertoires exhibit the aforementioned dynamics, although evidence for emergence was less certain. Importantly, this study shows that CDST dynamics are discernible in an individual's perception of their language development over time.

Les répertoires langagiers se comprennent traditionnellement comme un ensemble de compartiments déterminés chronologiquement (première langue, deuxième langue, etc.), un mécanisme qui maintient plusieurs problèmes de validité et d'éthique quand il est opérationnalisé dans la recherche et l'enseignement (Ortega, 2019). La théorie des systèmes dynamiques complexes (également appelée théorie de la complexité, ici TSDC) a été acclamée comme une solution pour avancer, mais son applicabilité à des contextes plurilingues devra être testée davantage. L'étude exploratoire suivante apporte sa contribution en examinant le fait de savoir si les propriétés inhérentes aux systèmes dynamiques complexes se manifestent dans les perceptions que les plurilingues ont de leurs systèmes au fur et à mesure que leurs systèmes de langue changent avec le temps. En se servant de la modélisation de la rétrodiction qualitative (Dörnyei, 2014), cette étude discerne la trajectoire de développement de systèmes langagiers changeants en travaillant à l'envers par le biais de données recueillies pendant une fenêtre d'observation. Pendant

une période de trois mois, trois personnes plurilingues ont évalué leurs systèmes langagiers au moyen de sondages hebdomadaires et ont participé à des entrevues ouvertes. Une analyse phénoménologique en trois étapes a évalué les données par rapport au prisme théorique de la TSDC afin d'identifier cinq propriétés de la TSDC (l'état d'attractivité, les changements de phases, la co-adaptation, l'auto-organisation et l'émergence) dans la perception que les participants avaient de leurs répertoires changeants. Les résultats indiquent que les répertoires plurilingues démontrent les dynamiques susmentionnées, bien que les preuves de l'émergence soient moins certaines. De façon importante, cette étude montre que les dynamiques de la TSDC sont discernables dans la perception que chaque personne se fait du développement de leur langue avec le temps.

Keywords: complex dynamic systems theory, language repertoires, multilingualism, plurilingualism, retrodictive qualitative modelling

This study provides empirical evidence that plurilingual language repertoires are dynamic systems whose subsystems (i.e., languages) demonstrate dynamic interactions over time. In what has been called “the multilingual turn in second language acquisition (SLA),” comprehensive and convincing critiques against a pervasive monolingual bias in applied linguistics have amassed for over 3 decades (see Bley-Vroman, 1983; Conteh & Meier, 2014; Cook, 1992; Klein, 1998; May, 2013, 2019; Ortega, 2013a, 2013b, 2019). One particularly pervasive feature of this bias, and the one emphasized in this study, is the notion that languages used by an individual exist within a one-dimensional, linear and chronological repertoire composed of a first language (L1), second language (L2), and subsequent languages (L_n ; henceforth known as the linear model).

The near ubiquitous linear model of language repertoires presents several validity and ethical issues when operationalized in research and education. Notably, it denies superdiverse language realities (see Blommaert & Backus, 2013; Todeva & Cenoz, 2009) and construes language growth as a static cumulation of endpoints rather than an unending process of variable development and attrition. Moreover, the linear model may erroneously compartmentalize languages, contradicting data which indicate that the lines between styles, registers, dialects, and languages are blurred (de Bot & Jaensch, 2015; Llama et al., 2010). Likely more damaging is that the additive nature of the linear model flies in the face of data showing that multilingual processing and development may be qualitatively unique from first-/second-language development (Cenoz, 2003, 2013; Hoffmann, 2001), perhaps due to differences in metalinguistic knowledge or awareness (Angelovska, 2018; Gibson & Hufeisen, 2011; Hofer & Jessner, 2016; Jessner, 2006, 2008).

Therefore, in keeping with the monolingual bias in SLA, the linear model erases consequential aspects of multi-language use (*plurilingualism*; see below). As a result, the only issue that truly distinguishes elements within the linear model is that of time. In this context, put most poignantly in Ortega (2013a), “SLA researchers are then free to imagine the nonnative speaking participants in their studies as budding monolinguals for the second time around, and their bi/multilingualism can be excluded from study designs” (p. 36).

A way forward has been triggered by the introduction of complex dynamic systems theory (also complexity theory and dynamic systems theory; here CDST) into the field of SLA (see de Bot et al., 2007; Larsen-Freeman, 1997; Larsen-Freeman & Cameron, 2008a). Fundamentally being a theory of change over time, CDST examines the emergent properties of complex systems that arise through the interaction of subsystem components (see forthcoming section). By applying CDST to language development, linguists and theorists have generated new conceptualizations of language repertoires as nonlinear, reversible, complex, adaptive, open and dynamic *systems* (see Herdina & Jessner, 2002) which is compatible with the plurilingual view of language competence (Piccardo, 2017). This application of CDST to holistic plurilingual language repertoires is justified in theory as the different languages, variants, and registers are posited to be dynamic subsystems within the overall language system of an individual (see Larsen-Freeman, 1997; Jessner, 2008; Lowie, 2017).

Still, as Dörnyei et al. (2015) note, little empirical work using CDST methodology has been done, and even less so when applied to the longitudinal development of holistic language repertoires. The fact remains that empirical evidence supporting CDST’s claim that languages are dynamic subsystems within a repertoire requires further documentation. To this end, this study makes a contribution by identifying signature dynamics (i.e., mechanisms within a system; outlined later) of plurilingual repertoires in development. To do this, we surveyed how three participants’ plurilingual systems evolved over a 3-month period, and then assessed these cases with Retrodictive Qualitative Modelling (RQM; Dörnyei, 2014; Larsen-Freeman, 2015; see method).

By applying CDST’s theoretical and methodological framework, this study has two interrelated goals. First, identify CDST’s dynamic properties within plurilingual repertoires. Second, in light of this, provide support for more dynamic conceptualizations of plurilingualism by problematizing the current use of the linear system in SLA and language education.

Background

Plurilingualism and Plurilingual Repertoires

Plurilingualism as a notion distinct from *multilingualism* was first outlined in *The Common European Framework of Reference for Languages* (CEFR; Council of Europe, 2001) and its supporting studies (Coste et al., 1997, 2009). Here, multilingualism denotes the languages within a geographical area or society while plurilingualism describes the uneven abilities of an individual to use more than one language to meet communicative needs (Council of Europe, 2001; 2020). Fundamental to plurilingualism is the concept of a plurilingual repertoire. In contrast to linear conceptions, this repertoire is seen as fluid, uneven, interconnected, and ever-evolving (Beacco et al., 2016) as individuals develop various linguistic resources, according to their agency and in response to constraints and opportunities (Marshall & Moore, 2018). In other words, the plurilingual view of language repertoires is harmonious with CDST's view, notably in how an individual's interrelated language resources arise over time within an ecology (Piccardo, 2017).

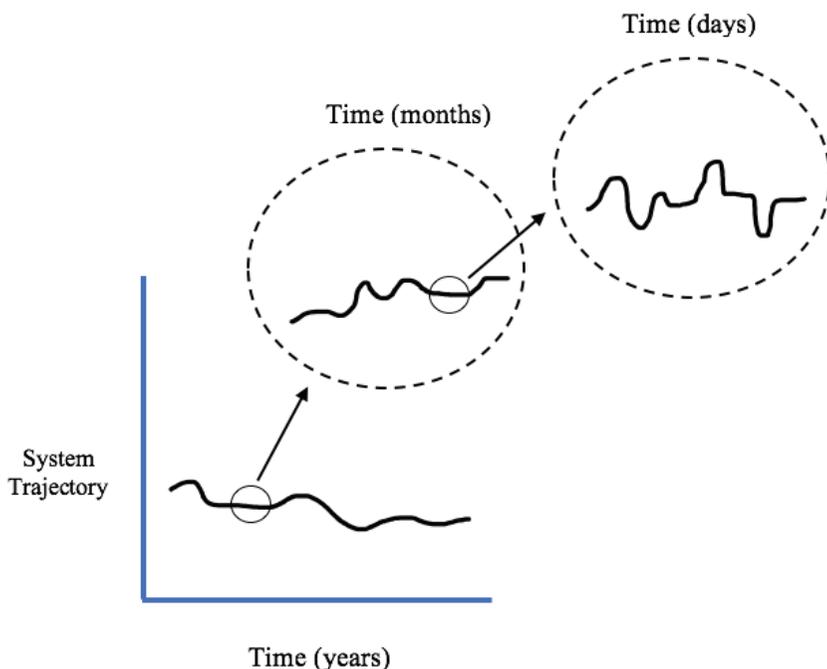
Drawing on research into plurilingualism, Piccardo and North (2020) also show that individuals can draw selectively or entirely from their linguistic resources during communication. Thus, even though the language resources of an individual's repertoire may be differential (i.e., in terms of proficiency and competency), this variation is a normal trait of plurilinguals and not a deficiency (Galante, 2020; Payant, 2020; Piccardo, 2019). This notion is encapsulated in the CEFR, whereby plurilinguals are said to have "a single, interrelated repertoire that they combine with their general competences and various strategies in order to accomplish tasks" (Council of Europe, 2020, p. 30). As such, this study adopts plurilingual terminology to emphasize the dynamic nature of the participants' multi-language use. As the terms plurilingual and multilingual have been used interchangeably in past literature, original terminology in citations is maintained.

Overview of CDST

CDST holds that dynamic systems arise from the complete interconnectedness of their subsystem components which are in a constant state of change (de Bot et al., 2007; Larsen-Freeman & Cameron, 2008a; Verspoor et al. 2008). Important to note is that this change is not only influenced by external energy (e.g., environmental factors like learning environment) from outside the system, but also by internal forces (i.e., subsystems adaptively interacting with, and to, each other). In other words, the components of dynamic systems are open but completely interdependent (de Bot & Larsen-Freeman, 2011). This adaptive interaction provokes dynamic systems to develop properties that render them more than the simple culmination of their individual elements (de Bot et al., 2007; Larsen-Freeman & Cameron, 2008a). Further,

dynamic systems are complex as their individual elements may be dynamic subsystems in their own right and be embedded within larger complex systems. Having nested levels of embedded complexity means that system dynamics can be viewed at different scales such as from the ecological down to the subatomic and be examined on timescales such as millennia down to nanoseconds (see de Bot, 2015). Figure 1 demonstrates how a system can be observably different depending on the timescale of observation.

Figure 1
A Visual Representation of a Dynamic System on Three Timescales (Adapted From Larsen-Freeman, 2015)



Language as a Complex Dynamic System

Since this study aims to provide support for a complex dynamic view of plurilingualism, certain theoretical and methodological considerations apply (see Dörnyei et al, 2015; Hiver & Al-Hoorie, 2016; Larsen-Freeman & Cameron, 2008b; Lowie, 2017; Verspoor et al., 2011). First, both plurilingualism and CDST challenge researchers to view language proficiency as an emerging

property of a dynamic system in constant flux. From this perspective, language proficiency changes continually and is not acquired, but developed. This means skill growth and skill decline are equally relevant (de Bot & Larsen-Freeman, 2011) and worthy of analysis. Moreover, for research into language development, it is essential to define the system under investigation (Hiver, 2015) given that CDST views language as an embedded system of human cognition whose subsystem components can span all levels of human organization (e.g., sociocultural, individual, neural) as well as all levels of language (e.g., lexical, phonological, syntactic; de Bot & Larsen-Freeman, 2011; Larsen-Freeman & Cameron, 2008a). It is therefore not feasible for a study to examine language development at all its nested levels.

Accordingly, this study observes language development at the level of holistic language repertoires, which Herdina and Jessner (2002) and Jessner (2008) have theorized as forming a multilingual system where the different languages, dialects, and registers are subsystems. Their Dynamic Model of Multilingualism (the DMM) holds that language systems exhibit continuous change and nonlinear growth because an individual's resources (time and energy) are limited. In other words, the stability of a language system is dependent on the resources invested into the system, and its maintenance therefore adjusts to the perceived communicative needs of the individual in response to internal and external factors. Additionally, the DMM argues that transfer from one language system can lead to divergent results in other language systems of the same speaker due to dynamic interactions (see below) among various interdependent subsystems.

Somewhat surprisingly, this scale of investigation has received comparatively little research attention within CDST. One exception is Opitz (2017), who performed an ad hoc CDST interpretation of four previous studies on multilingual development. She concludes that all languages in a multilingual system exhibit variability at all timescales examined, but that they may enter stasis under favourable conditions. In terms of this variability, the author observed S shaped growth trajectories in three studies (see also Herdina & Jessner, 2002, for a similar claim), which suggests that highly developed languages are more stable than low-proficiency languages, and that the former take longer to regress and less effort to maintain.

Unlike the current study, most L2 research using CDST methodology has been conducted on a more macro level involving motivation (Dörnyei et al., 2015), self-concept (Mercer, 2014), and willingness to communicate (MacIntyre & Legatto, 2011), or a more micro level focusing on the emergence of L2 linguistic constructions (Ellis & Larsen-Freeman, 2009; Larsen-Freeman, 2006), L2 accuracy and complexity (Spoelman & Verspoor, 2010), variability of L2 constructions (Verspoor et al., 2008), patterns of L2 lexical and syntactic development (Verspoor et al., 2012), and L2 writing fluency measures (Baba & Nitta, 2014; Polat & Kim, 2014). Additionally, most CDST research spotlights the development of only one language system, even if their participants may

possess multiple (for exceptions, see Huang et al., 2020; Lowie et al., 2014, Plat et al., 2018, and Yang & Sun, 2015).

Signature Dynamics of Complex Systems

After having defined the complex system in question, one way to make sense of it is to analyze the dynamic interactions between its subsystems over time (Lowie, 2017). An appropriate way to do this is to track subsystems as they inevitably undergo periods of variability (van Dijk et al., 2011). By discussing this variability in light of CDST's key constructs (e.g., state-space, attractor states, perturbations, phase shifts, self-organization, co-adaptation and emergence), these patterns of dynamic subsystem interaction can be conceptualized (and then examined) as change occurs within a language repertoire.

State-Space, Attractor States, and Perturbations

CDST represents system change as movement across a state-space, which can be conceived as a two- or three-dimensional representation of all possible states or configurations that a particular system can be in (see forthcoming Figure 3 and related discussion). As a spatial metaphor, a "state-space" is the "landscape of possibilities" (Larsen-Freeman & Cameron, 2008a, p. 47) through which a system can roam (Henry, 2015), and this may be wide-ranging, but certainly not infinite (Larsen-Freeman, 2015). For languages, the state-space can range from no proficiency to the strongest command (the upper limit is vague, but not endless). Within this state-space, we can find the system's attractor states which signify a particular mode of behaviour towards which the system tends to move over time (Hiver, 2015; Larsen-Freeman & Cameron, 2008a). Attractor states are therefore pockets of stable behaviour that nonetheless exhibit some degree of variability as change is constant (Hiver, 2015; Spoelman & Verspoor, 2010). A system leaves its attractor state in response to a perturbation or a disrupting force that "jolts" a system towards a new state of being (Hiver, 2015). If a system resists change in the face of a particular perturbation, it is said to be in a strong attractor state. Systems in weak attractor states are susceptible to disturbances and can be thrown out of equilibrium. This can be evidenced by increased variability in the (sub)system's trajectory through state-space (Verspoor et al., 2008).

As it pertains to pluri-/multilingual development, Opitz (2017) illustrates this construct from a CDST perspective. By examining her participants' language repertoires at different time scales (days, weeks, months, years), she found that all languages showed variability over time but that the magnitude of this change differed. Usually, one part of the pluri-/multilingual system showed relative stability. Still, participants in two studies faced the major perturbation of migrating to a new linguistic environment which, over time and L2 exposure, gave rise to phenomena (e.g., inappropriate L1 language

use) suggesting that even systems in strong attractor states (L1s) became unsettled. More persistent displays of attrition in both L1 and L2s occurred later in the form of retrieval difficulties and crosslinguistic influence.

Phase Shifts, Self-Organization, and Emergence

Pertinent to this study's analysis is the identification of phase shifts, self-organization, and emergent properties. When a perturbation is strong enough to destabilize a subsystem out of its attractor state and into another, a *phase shift* has occurred. This phenomenon brings about new modes of behaviour which alter the larger system in ways which are qualitatively and observably different than before (Henry, 2015; Larsen-Freeman & Cameron, 2008a). In this light, Spoelman and Verspoor (2010) examined the morphosyntactic and lexical complexity of 54 writing samples of a Dutch learner of Finnish over the course of 3 years. The researchers reported a sudden and significant developmental jump in noun-phrase complexity between two of their participants' later samples, indicating a phase shift occurred at that time.

After a phase shift, the internal dynamics of a system cause it to spontaneously restabilize into a new attractor (Larsen-Freeman & Cameron, 2008a). This assembly of new order (i.e., a stability) is known as *self-organization* when caused by internal system dynamics, as opposed to external factors that force the new pattern of behaviour (Larsen-Freeman & Cameron, 2008a) and is evidenced by a higher-order function (Hiver & Al-Hoori, 2016). Furthermore, self-organization may lead to the spontaneous occurrence of new patterns due to the dynamics of the system itself (van Geert, 2008), which is a phenomenon known as *emergence*. Returning to the DMM, Herdina and Jessner (2002) and Jessner (2006) argue that enhanced metalinguistic awareness and its interlingual counterpart, crosslinguistic awareness, is a property that emerges from the inherent interaction between the language subsystems of a multilingual.

Co-Adaptation

Co-adaptation emphasizes the complete interconnection between (sub) systems. Specifically, it denotes system changes that are motivated by change in another connected system when the former's trajectory roams into the latter's state-space landscape (Larsen-Freeman & Cameron, 2008a). In the case of multilingual development, Herdina and Jessner (2002) argue that contact between two or more languages does not simply cause overlap of these systems but provokes a "metamorphosis" of all language systems involved. Importantly, some subsystems are more strongly connected than others (de Bot & Larsen-Freeman, 2011). This means identifying the co-adaptation of subsystems can involve assessing the mutual impact of a perturbation and particularly if the development of a certain system becomes a perturbation affecting others. To our knowledge, no study has yet examined whether these

five CDST dynamics manifest in the perceptions that plurilinguals have of their own changing repertoires.

The Current Study

This study examines the CDST claim that languages within a repertoire are interlinked subsystems of an overall pluri-/multilingual system (Herdina & Jessner, 2002; Jessner, 2008). To this end, it investigates the developmental dynamics of three plurilingual individuals who are actively learning another language. Since CDST holds that all dynamic systems are in a continuous state of flux and that “all changing subsystems can potentially and continuously interact with all other changing subsystems” (Lowie & Verspoor, 2015, p. 73), the exact array of components (i.e., languages, varieties) that make up the repertoires of these participants does not need to be controlled because the focus is the dynamics between systems, not their make-up. Additionally, following CDST and plurilingual theory, we do not conceive language development as end-point language accumulation (the linear model). Instead, development is viewed as participant reported changes in language (sub) systems over time as well as the interaction of such systems. The methodology outlined below analyzes such change and interaction qualitatively with RQM as a research template and CDST as an investigative lens. This design afforded the ability to assess whether plurilingual repertoires are indeed dynamic systems with the following research question:

Do the properties of complex dynamic systems (i.e., attractor states, phase shifts, self-organization, co-adaptation, and emergence) manifest in the perceptions that plurilinguals have on their own language development over time?

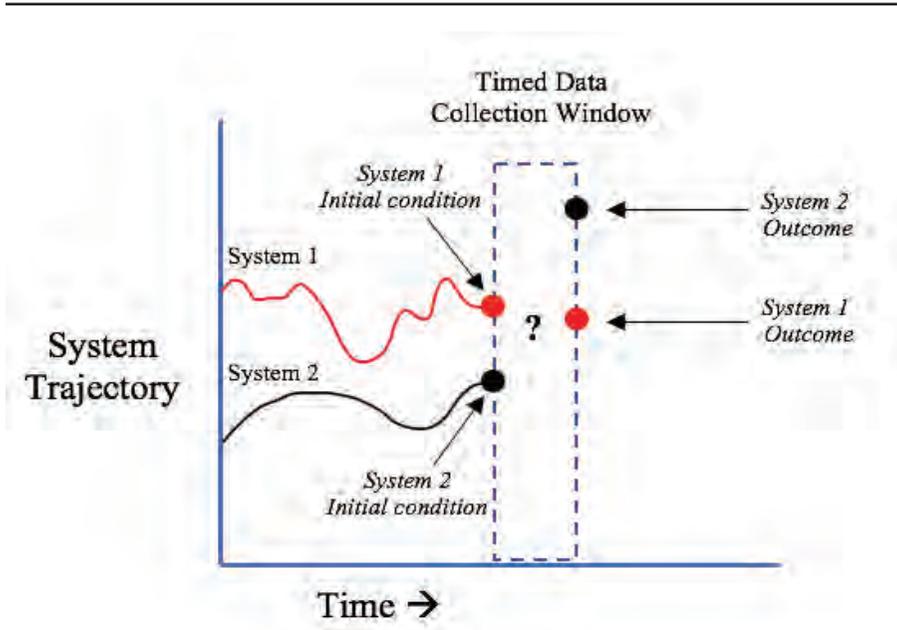
Method

Research Design

Complex systems are unpredictable because their trajectories are nonlinear (Larsen-Freeman & Cameron, 2008a). Consequently, this study employs RQM (Dörnyei, 2014; Larsen-Freeman, 2015; see Figure 2) to make sense of how a complex system arrives at a distinct outcome after change has occurred (for examples, see Chan et al., 2015; Henry, 2015; Hiver 2017). RQM reverses the order of traditional research. Instead of predicting the result of a treatment, analysis begins by identifying a system’s initial conditions (i.e., state and context; see *system 1 initial condition* in Figure 2), followed by its outcome after a period of time (see *system 1 outcome* in Figure 2). From here, a developmental trajectory is discerned by working backwards through data collected during

a 3-month observation window, which in our case involves interviews with participants and their longitudinal perceptions of proficiency.

Figure 2
RQM Study Design



Participants

Initially, five plurilingual adults were selected from a pool of 43 individuals after a call for participation was sent to a university in Montréal, Canada. None of the participants were known to the researchers or, as it turned out, students at the targeted university. These participants were chosen because they were operating in multilingual ecologies (i.e., settings) where they were required to use multiple languages in both their personal and professional lives to communicate. This increased the likelihood that they would engage, at least orally, in numerous languages across their repertoires during observation. Crucially, each reported actively learning an additional language. These two criteria allowed us the best possible chance to observe theorized CDST dynamics (see research question) within and between the interrelated elements of a given language repertoire. Although not a requirement for participation, the principal researcher could speak most of these individuals' languages (including target languages), which allowed for deeper insights during interviews. The data from two participants were excluded from this study. During analysis it became clear that these participants did not make progress in learning their new language, and, unlike the remaining

participants, only used one or two of the languages in their repertoire. As such, their insights hinged on speculation about hypothetical language use and past learning, neither of which is suitable for this study's use of RQM, which required perceptible changes in language repertoires over time. To be clear, since their language repertoires remained very stable, the potential to observe dynamics like phase shifts and co-adaptation during the observation window was basically moot. The final three participants, Larisa (28, female), Ramin (30, male) and Coralie (26, female; all pseudonyms) self-disclosed as plurilingual learners at different stages of developing a new language (see Table 1).

Table 1
Overview of Participants

Name	Languages	Birthplace / Longest Residence	Residence During Observation
Larisa	Catalan (C2*) > Spanish (C2) > English (C1/C2) > Norwegian (B1/B2) > German (B1) > Russian (A2)**	Catalonia / Spain	Trøndelag, Norway
	Catalan/Spanish (simultaneous), English, German, Russian, Norwegian***		
Ramin	Farsi (C2) > English (C2) > French (B1)	Tehran / Iran	Toronto, Canada
	Farsi, English, French		
Coralie	French (C2) > English (C2) > Spanish (B1) > Italian (A1)	Québec / Canada	Montréal, Canada
	French/English (sequential), Spanish, Italian		

* Self-reported language proficiency, CEFR (2020)

** Order of dominance: > signifies the individual is more proficient in the preceding language

*** Order of learning: the individual was actively learning the language in bold during data collection

Instruments

Questionnaire and Initial Interview

To identify the initial conditions of language systems so that development could be tracked, participants first completed the Language Experience and Proficiency Questionnaire (LEAP-Q; Kaushanskaya et al., 2019; Marian et al., 2007), which is a validated instrument that ascertains language profiles and backgrounds. Afterwards, language proficiency was equated to CEFR levels and verified with each participant in a recorded, online interview over Zoom, where additional interview questions were asked (adapted from McAdam's 2007 Life Story Interview; see Hiver, 2017).

Open-Ended Interviews

RQM requires that data with a time element be collected during an observation window so that system dynamics informing a developmental trajectory can be reconstructed (see Figure 2). For this, biweekly interviews with the participants were conducted online through Zoom. The interviews occurred mostly in English as each participant reported mastery (CEFR C2) in the language. However, participants regularly moved between languages to both express thoughts and describe perceptions. To avoid priming participant responses, these interviews were very loosely structured and began with a leading question that asked participants to describe the languages they had spoken since the last interview, with whom, and under what circumstances. From there, participants were asked to share their experiences, observations, and perceptions related to both the language they were learning and the languages they were using. These interviews were recorded and transcribed verbatim.

Self-Assessments of Speaking Automaticity

Once per week over the course of the study, our participants self-assessed their oral production in each of their language systems. As plurilingualism views language competence as a dynamic flux of uneven functionality within languages and across activities ("*partial competence*"; Coste et al., 2009; Council of Europe, 2001; 2020), oral production was chosen over other modes of communication (e.g., written production) because we did not expect our participants to use all their languages in all modes each week.

Oral production was broadly operationalized as "speaking automaticity," which we defined as the mental effort and reflection required to produce language. This construct was chosen as it could operationalize variation in *perceived* speaking performance in a way that was easily understood and reported by the participants. Since perception is unique to each individual, we avoided the use of more common external benchmarks or descriptors (e.g., grammaticality, CEFR descriptors) so as to not confound our participants'

understanding of these external benchmarks/descriptors with what they felt. Participants rated their speaking automaticity using a sliding scale sent to them weekly via a personalized online survey. The extreme ends of the scale were labelled as less automatic (“0; intense effort to think about words, meaning or structure of your language”) and more automatic (100; producing language with little or no reflection on the words, meaning or structure). These data were used as a point of comparison against the perceptions shared during the interviews and as another way to gain insight into both language system stability (i.e., attractor states) and co-adaptation.

Procedure

Over a 3-month period, individual online interviews took place every 2 weeks (16 interviews total; 6 with Larisa, 5 with Ramin and Coralie). Each interview lasted approximately 30 minutes, except for the initial interview which took approximately 1 hour. Participants self-assessed their perceived speaking automaticity in each language every 7 days through an online survey resulting in 9 assessments for Larisa, and 7 for Ramin and Coralie. The individualized nature of our data meant we could keep the extra data points for Larisa who began observation early and was willing to continue 2 weeks longer.

Data Analysis

Analysis of Self-Assessments of Speaking Automaticity

Analysis of the speaking self-assessments follows the approach outlined in van Dijk et al. (2011) and Lowie (2017). First, data were plotted descriptively to chart trends in subsystem fluctuations. Next, a simple min-max technique was used to locate the bandwidth value between the maximum and minimum values which charts the amount of variation in each subsystem over time. The wider the bandwidth of each subsystem, the greater the amount of variation. Given the introspective nature of these qualitative data and the few data points, they are not robust enough for further statistical analysis.

Analysis of Interview Data

Interview data underwent a three-stage phenomenological analysis using MAXQDA software guided by Smith and Eatough (2007) and Smith and Shinebourne (2012). First, in an iterative process, the transcripts were read and reread before open-codes were assigned to phenomena related to our participants’ language experiences, perceptions, and observations (e.g., “new recurring speaking opportunity”; “uncontrolled language transfer”). Simultaneously, we flagged the language(s) that the participants referred to using an individualized language coding system. For example, when Ramin reported surprise that some French (L3) words began coming to mind when

speaking English (L2), the codes “Ramin: English” and “Ramin: French” were used alongside the open-code “novel language influence.” Second, we compiled the open-codes into thematic clusters (e.g., “consistent language use behaviour”; “influential individuals”). Steps one and two allowed us to examine which of our participants’ languages were more (or less) present in any given theme. The final stage evaluated the generated themes against the system dynamics inherent to dynamic systems outlined in the background section.

Preliminary Findings

System Components

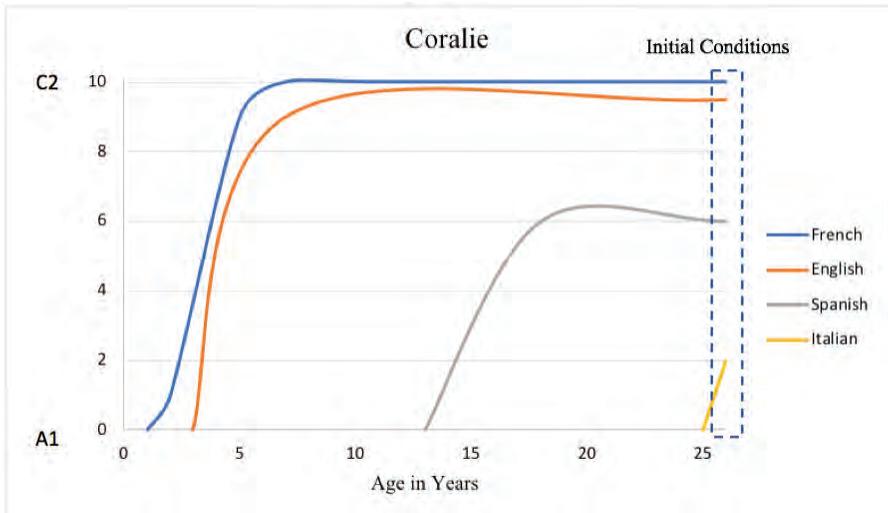
Before analysis could begin, we needed to identify what we counted as a language system within the superdiverse realities of language repertoires (a critical requirement of RQM; Hiver, 2015). Next, we needed to uncover the initial conditions of our participants’ language subsystems. To begin, language systems for this study were conceived as the languages over which our participants implied a sort of ownership through use and delineated according to what they conceived as a language entity. For Example, Larisa demonstrated keen knowledge of some Norwegian dialect features that had begun to influence her standard Norwegian that she repressed. She further stated that her use of such forms was “only passive.” This indicated that her conception of the Norwegian language included a multiplicity of dialect variation, but that her Norwegian was currently anchored around a standard form. In short, conceptions of what “should” constitute a language system were not imposed. Instead, language systems were located in how the participants conceived their own repertoires from the interview and questionnaire data.

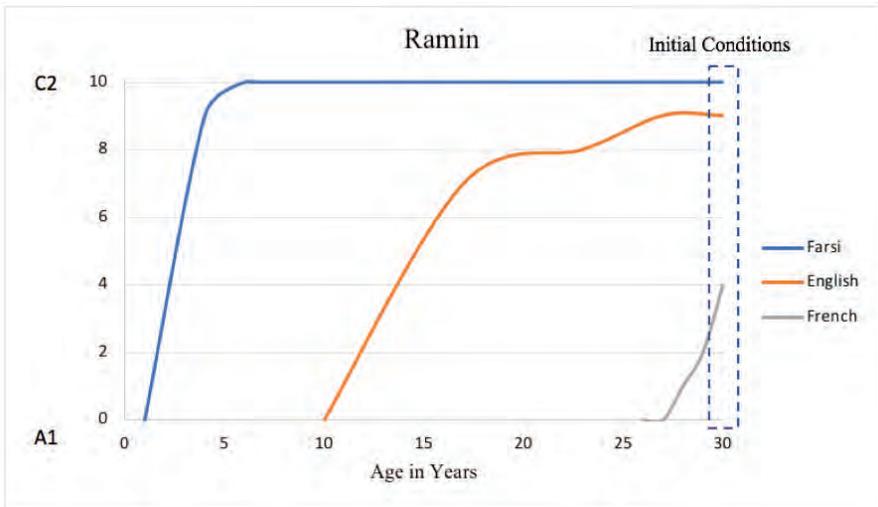
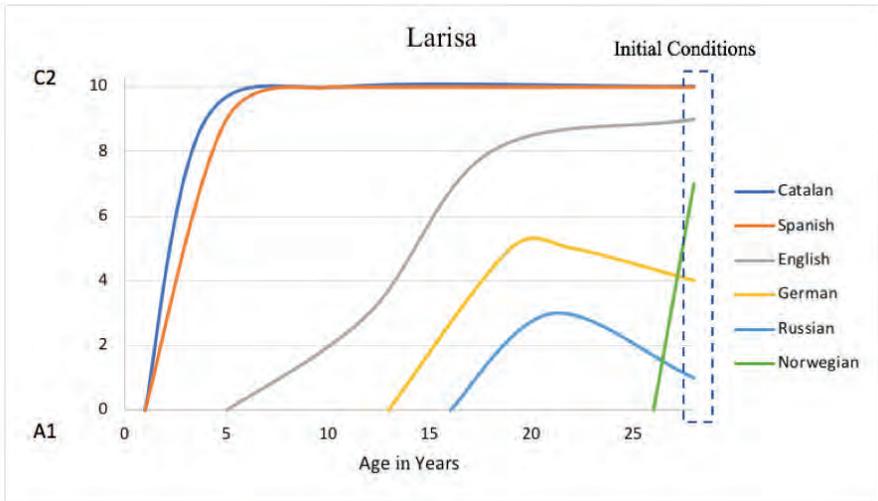
Initial Conditions of System Components

Once language subsystems were identified, their initial conditions (i.e., state of being within the holistic repertoire; comparative proficiencies) needed to be determined so that their development could be examined during analysis. For this, a graph was generated for each participant that traced the development of their language systems from birth so that a state-space landscape could be conceived for their repertoire (Figure 3). This was done with data from the LEAP-Q questionnaire and subsequent interviews. Although the graphs oversimplify state-spaces to one timescale (years) and ignore elements such as modality (e.g., production vs. comprehension), they confirmed the initial conditions of subsystems where the graphs end (see *Initial Conditions* in Figure 3). Skipping this step would promote reductionism that is contrary to a CDST approach (de Bot & Larsen-Freeman, 2011).

For Figure 3, the maximum and minimum values on the Y axis represent a state-space configuration delineated by CEFR (Council of Europe, 2001; 2020) descriptors ranging from C2 (Mastery; fine conveyance of precise meaning and appropriateness) to A1 (Breakthrough; simple interaction and formulaic statements on familiar topics), respectively. Upward trends represent periods of perceived language learning and growth (e.g., during work or student exchange experiences) while downward trends show periods of decline or regression in perceived proficiency.

Figure 3
Repertoire Development as a State-Space over Time and Initial Conditions of Subsystems





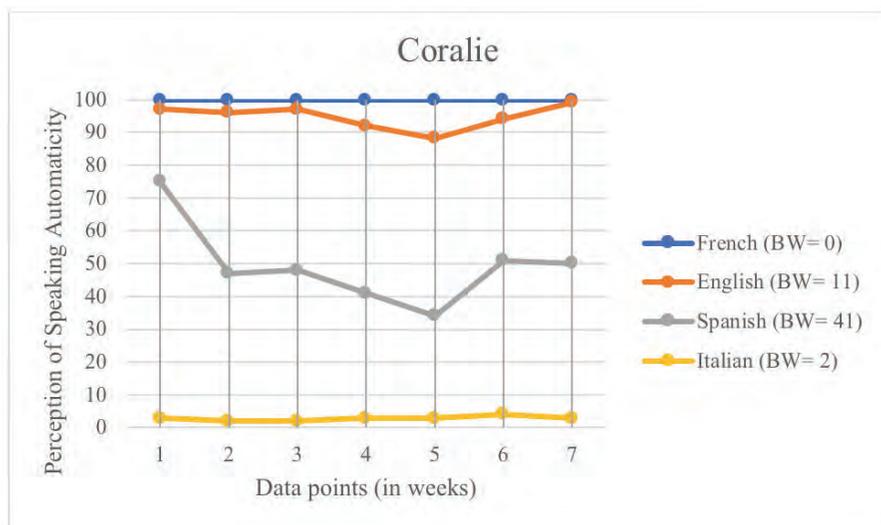
Findings and Discussion

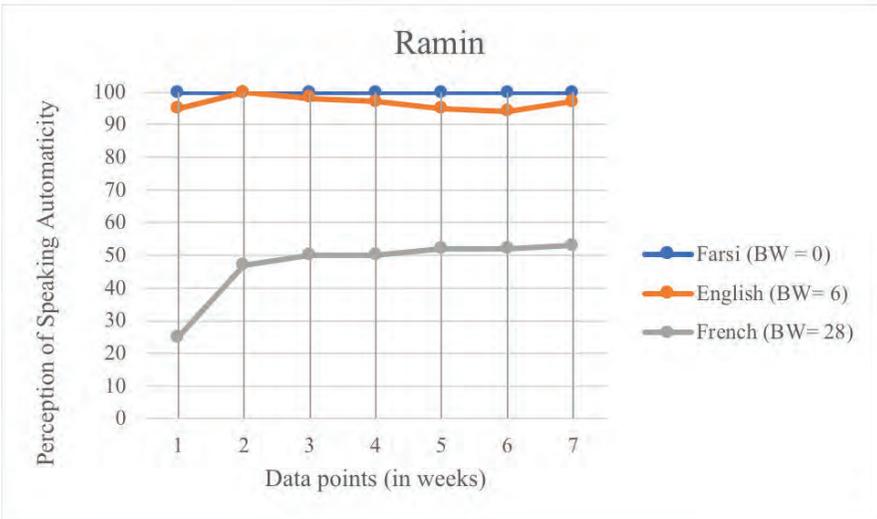
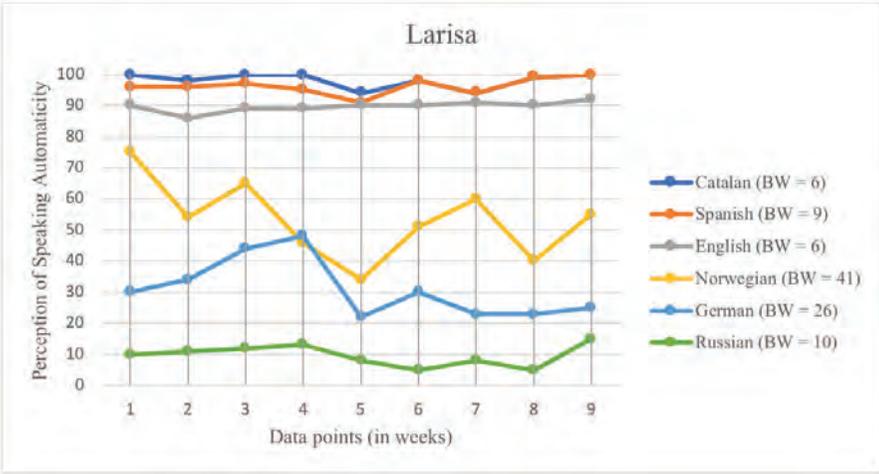
The following section combines the traditional Findings and Discussion sections. Given that the analysis aimed to identify and explain reported language development in light of five CDST dynamics, it made little sense to present our findings independent of an interpretation. The section sequentially presents evidence for how these subsystems exhibited the five target properties: attractor states, co-adaptation, phase shifts, self-organization, and emergence.

Evidence of Attractor States

To determine whether languages are complex dynamic systems, this study's research question asked if CDST's signature constructs can be identified in how individuals perceive their changing repertoire over time. The results begin with evidence for attractor states. Determining whether attractor states manifest in plurilingual repertoires required two steps. First, we needed evidence that the language systems of a plurilingual individual exhibit different degrees of variability. Second, our RQM analysis needed to show that this variability had consequential impacts on how a plurilingual system developed. Both of these requirements were satisfied. To begin, data in Figure 4 show our participants' self-assessments of speaking automaticity in all their language systems over a 3-month period. Here, we observed that language systems varied differentially over time as shown by their bandwidth values (BW; see method section) where higher fluctuations of automaticity resulted in higher bandwidth values and vice versa. In CDST, strong and weak attractor states are synonymous with low and high variability respectively (Hiver, 2015); consequently, we would consider, for example, Coralie's English (BW = 11) to be in a stronger attractor state than her Spanish (BW = 41).

Figure 4
Self-Assessments of Perceived Automaticity when Speaking





Next, our qualitative data show that these supposed attractor states influenced the development of repertoires in two ways, as hypothesized by CDST (see Hiver, 2015; van Dijk et al, 2011). First, systems in hypothesized strong attractor states appeared more resistant to decay. Second, such systems seemed to better withstand perturbations.

For these two points, Ramin’s English (BW = 6) and Larisa’s Norwegian (BW = 41) offer evidence as contrastive examples. Ramin shared that his use of English (in a hypothesized strong attractor state) dropped immediately after graduating from university 1 year earlier yet affirmed that he did not notice much change in his spoken English during observation given this

new pattern of use. Contrastively, Larisa attested to the susceptibility of her Norwegian (in a hypothesized weak attractor state) to perturbations such as those caused by social distancing measures of the COVID-19 pandemic: “these last two days, I felt like my Norwegian was going back a little bit.” Larisa offered no such comments for her English whose use was also impacted by these measures (albeit less so), or her Spanish, a language that is also in a hypothesized strong attractor state and one she spoke less frequently than both English and Norwegian.

Moreover, Ramin’s French system provided an interesting case for how hypothesized strong attractor states coincide with a resistance to decay even when the system is not highly developed. For example, quantitative data (see Figure 4) indicate that Ramin’s French system was highly variable in automaticity for the first set of data points and then levels out. Qualitative data later reveal that Ramin’s French became better attuned to its principal situation of use (i.e., settled into a new attractor) soon after data collection began, due to the routine and stable nature of the twice-weekly private French lessons that he had begun a month earlier. For instance, after speaking emphatically about his new French learning routine and speaking activities with his tutor, he described his language learning as moderate in later interviews and no consequential perturbations were identified for his French system. This indicates that his French had likely become fit to its context. Consequently, CDST may see this new stable attractor state as a reason why Ramin’s French was not impacted by breaks from his usual dedicated routine.

This contrasts starkly with Larisa’s experience with Norwegian where she perceived a regression in language within a matter of days. This is peculiar, as Larisa’s Norwegian appeared more advanced than Ramin’s French when these participants spoke these languages with the researcher. To explain this from a CDST perspective, our analysis indicates that it is not only a system’s state of development that regulates rates of decay, but its attractor state (i.e., fitness to an environment, degree of variability) also plays a role. For example, the continual demands on Larisa’s Norwegian, particularly in the form of workplace meetings at her new job, were consistent themes in her interview data and flagged as perturbations that destabilized her Norwegian system as she adapted to a new communicative environment. From a CDST stance, it could have been this weakening of an attractor state that contributed to her Norwegian’s decline, or at least perception of decline, as the system experienced unstable habits of use.

Still, a question remains. How to reconcile the data from the speaking self-assessments (Figure 4) that show less developed language systems exhibit narrow bandwidths of variation much like systems in strong attractor states (e.g., Russian for Larisa and Italian for Coralie, $BW = 10$ and 2 , respectively)? CDST theorizes that such language systems would likely be in low attractor states evidenced by potential to decay and increased variability (Larsen-Freeman & Cameron, 2008a). Our qualitative data for Coralie indicate that

this is still the case as she reported, “so few building blocks [in Italian] that [she] just forget[s] them all and [she] can’t build anything with them.” As such, we need to set aside the speaking self-assessments for less developed languages. This is not surprising as Coralie reported that her speaking automaticity for Italian was essentially nil: “unprompted, I have no idea how to say any words.”

In sum, data for Larisa, Ramin, and Coralie preliminarily substantiate the applicability of attractor states to holistic language repertoires; all participants reported subsystem behaviours that reflect the hypothesized nature of how such subsystems would act according to the properties of attractor states, as attested in de Bot & Larsen-Freeman (2011) and Hiver (2015).

Evidence of Co-Adaptation

The RQM analysis considered whether the CDST construct of co-adaptation applies to plurilingual repertoires in development. As defined earlier, co-adaptation pertains to the interconnection between (sub)systems and how change in one system is motivated by change in another. To this end, we note two trends in our data for Coralie and Larisa that uphold this. First, we saw how the nature of variability in plurilingual repertoires seemed to be a function of the array of subsystem components themselves. Second, we saw how the growth of one language system provoked changes in others that seemed to hinge on systems sharing a similar state-space landscape (Figure 3).

Coralie’s system offers an example for the first point regarding variability as a function of system components. Here, the precarious existence of Coralie’s Italian neither precluded it from variation nor sealed it within a vacuum. Instead, variation seemed to be pulled from other language systems. For instance, themes in Coralie’s data indicate high variation in her Italian pronunciation, which she explicitly stated to be motivated by her Spanish, such as the “dreaded [i]/[ɛ] issue” where she “keep[s] saying /i/ everywhere instead of saying /ɛ/.” Increased variation that is provoked by the existence of another language within the same repertoire speaks to the interconnectedness of systems and satisfies the theorized process of co-adaptation. Put plainly, this phenomenon would not have occurred if Coralie did not have a preexisting Spanish system. Indeed, this kind of variation could be a hallmark of plurilingual language learning, echoing the observation in Huang et al. (2020) that L3 learners experience more variation in their L2 writing fluency than L2 writers without an L3 system. From a developmental perspective, this phenomenon could be a prerequisite for the overall plurilingual system to adapt to the growth of a new subsystem.

As for the second point of evidence for co-adaptation, our qualitative data are clear that the coexistence of German and Norwegian in Larisa’s repertoire (see Figure 3) increased variation in both systems. This variation

was most visible as an unevenly reciprocal crosslinguistic influence that seemed regulated by use and system growth. For example, Larisa reported trying to overcome German's influence on her Norwegian by regulating its use: "I may have to try to not speak so much German for a while because it's true that, if I speak more German my Norwegian gets worse." Reversely, Larisa also reported how growth in her Norwegian system was having an increased impact on her earlier developed German system (i.e., a shifting direction of influence): "The problem is that [now] my Norwegian is affecting my German."

It seems fitting to say that this mutual impact of systems is an example of co-adaptation. However, is this process ignited by one system roaming into another's state-space landscape as theorized by CDST (Larsen-Freeman & Cameron, 2008a)? For this, we do note that Larisa reported a proficiency in Norwegian that had recently surpassed her proficiency in German. In other words, it recently crossed German's path within the state-space of her repertoire (see Larisa in Figure 3). Further, Larisa also shared memories of phenomena that occurred before observation, which align with the theory that crossing state-space trajectories provokes co-adaptation. Specifically, she recalled how she would "blurt out words in Russian" (her L5) when she first began learning Norwegian (her L6). She then described how German (her L4) overtook Russian as the dominant influence on her Norwegian system. Thus, the increased language interaction reported above is in harmony with CDST and potentially adds a new dimension to current research trying to uncover factors which regulate crosslinguistic influence (see Gujord, 2020, for a recent review of transfer constraints).

On that note, our RQM analysis suggests that more is at play than crosslinguistic influence when such language interaction is viewed through a CDST lens. Specifically, we observed how an elevated control via an awareness contributes to a language subsystem's stability (i.e., it creates a strong attractor) and safeguards it from being impacted by change (i.e., growth or decline) in a different system. For example, Larisa reported repressing Norwegian's influence on her English "the moment that [she] noticed" it had begun to sound "Norwegian-y." The potential power of linguistic awareness as a regulating force of co-adaptation was also evidenced by Coralie. In her last interview she described how she began to separate Italian and Spanish in her mind: "I stopped trying to make those connections as much as I was making them originally."

Although no supporting research into crosslinguistic influence from a CDST perspective could be found, this finding does endorse Herdina and Jessner (2002), who theorize that metalinguistic awareness is an emergent property of multilingualism that arises from increased language interaction in a multilingual mind. There is certainly more than one way to explain the behaviour of Larisa and Coralie's language systems, but from the view of CDST, it appears that co-adaptation is a suitable construct to make sense of

changing plurilingual repertoires. Our data indicate that the mere existence of another language may provoke variation in others, and that change in one language can drive change in another, particularly when the former crosses the state-space trajectory of the latter. Moreover, subsystem interconnectedness can be directed by language awareness.

Evidence of Phase Shifts

To satisfy CDST's view on phase shifts (i.e., sudden new modes of behaviour that are qualitatively different than before) only new language behaviour representing a novel functioning ability within one language (or between languages) was identified as evidence that a phase shift had occurred. To begin, Ramin reported how his French now enables him to do things differently with English when it comes to a purposeful command of register. He noted: "there are some French words that are pretty common in French but are not common in English. They are kind of considered fancy words in English and I've started to use them a little bit in my writings." This change in writing behaviour could prove consequential for how Ramin uses English in a more general sense; accordingly, the change was labelled as a phase shift. Although the nature of the phenomenon is different, this finding shadows the higher-order patterns in writing fluency that Baba and Nitta (2014) labelled as phase shifts in their CDST study on writing development.

In another example, a turning point in how Larisa's Norwegian system interacts with its environment is seen in how she interprets her growth in Norwegian during workplace meetings. At the start of observation, she described these meetings as a source of anxiety, but later reported less reluctance to engage in Norwegian and a stronger sense of presence. Larisa spoke of this change in the context of a novel heightened awareness of how the Norwegian language is used around her. For example, she described how previously learned words and expressions "jump out at [her]" in this new environment and that she finds herself recycling this language as a means of propelling her Norwegian forward. She reported, "this encourages me because I feel like there's some loop going on in my head." We interpret this phenomenon as a phase shift, as it goes beyond the learning and subsequent use of discrete language elements (e.g., lexemes, grammatical structures). It represents a novel functioning of the open language system itself whereby a more effective feedback circuit promotes proficiency faster than before. Larisa's example is congruent with CDST, which posits that "complex dynamic systems do not remain passive in light of changing events; they 'learn' or adapt to an ever-changing environment" by way of feedback sensitivity (Larsen-Freeman, 2015, p. 16).

Evidence of Self-Organization

To identify evidence of self-organization in our dataset, we considered whether the internal dynamics of a system created a condition by which the system could achieve a more stable existence (i.e., order) within its environment. Specifically, a pattern of behaviour was seen as self-organized if it was provoked by the system itself rather than directed by an external force (e.g., perturbation). For this, we note how Larisa's Norwegian language system reached a state where it could now feed its own development within her environment, namely by giving Larisa more access to Norwegian. For example, Larisa reported that since her arrival in Norway, most Norwegians would speak to her in English. However, an increasingly important theme in her data shows a rise in the length and depth of her interactions in Norwegian as people realized she could communicate in the language. By providing evermore exposure to Norwegian, this creates a type of positive feedback loop that could be consequential for this system to avoid entropy within its environment (i.e., decays through lack of use or learning). Given the near ubiquitous levels of English bilingualism in Norway, which can feasibly deny learners exposure to Norwegian (a reality noted by Larisa herself), this mechanism of stability could prove definitive for this system's survival.

To these authors' knowledge, no SLA studies have examined such a mechanism empirically. However, CDST theorizes that new patterns of organization and attractor states arise from change that is caused by system interaction with an environment (de Bot & Larsen-Freeman, 2011; Larsen-Freeman, 2017), which supports plurilingualism's ecological view of language development and pedagogy (see Marshall & More, 2018; Beacco et al., 2016; Larsen-Freeman & Todeva, 2021). In short, shadows of evidence for self-organization were seen in Larisa's data, but less so for Ramin and Coralie. Neither of these individuals were living in an environment where their target languages were spoken and thus their respective contexts may not have been conducive for such mechanisms to take flight during the observation window.

Evidence of Emergence

Lastly, our analysis evaluated whether the CDST construct of emergence (i.e., the spontaneous occurrence of new patterns of behaviour that arise from system dynamics; van Geert, 2008) manifests in plurilingual repertoires. Here, evidence for emergence is tenuous in our dataset, likely due to the nonlinear characteristics of the five dynamics which cannot be fully isolated from one another. In other words, our limited data and analytical approach did not allow us to tease apart the construct of emergence from other dynamics, which, in the end, could be a futile exercise. Larsen-Freeman (2016) is clear that isolating part of a complex system for closer study (i.e., reductionism) removes patterns of connection. For this reason, phenomena which constitute emergence was likely confounded with other dynamics

(e.g., self-organization) and reported as such. An alternative perspective is that there are still unresolved theoretical constraints on what should count as emergence in applied linguistics. For example, offering a view from outside SLA, Beisbart (2021) argues that the field has not yet come to a common understanding of the term “emergence,” which echoes Berthele and Udry’s (2019) argument that evidence for the construct is often “formulated on purely theoretical grounds” (p. 14).

This said, we do see patterns in our data that could denote spontaneous emergence due to interacting language systems. For example, some of Ramin’s insights demonstrate an increased language awareness enabled by his new French system (see discussion on phase shifts above). He also expressed a newfound conception of etymology: “I’ve also thought about ... other languages in Farsi ... other words with different origins.” These realizations were reported as novel and important by Ramin and a product of his own internal observation. However, we cannot confirm that these would be beyond his grasp had French not entered his previous Farsi-English language system.

As for Coralie and Larisa, both demonstrated deep understandings of language from the earliest moments of data collection that seem to have emerged from complex interactions between their language systems. For example, when explaining why she thought knowing English (her L2) made learning Italian (her L4) easier, Coralie demonstrated an awareness of semiotics that she felt was consequential: “The ability to be like ... this item is represented by two words, or this action is represented by two words, like the ability to understand that concept ... is instrumental.” To explain why these reported insights cannot yet be confidently reported as emergence, one could support Beisbart’s (2021) critique on complexity theory’s application to multilingualism. He argues that CDST’s current fuzzy notion of what counts as new or unexpected phenomena or state transitions makes emergence too difficult to identify.

Conclusion

To determine whether languages are complex and dynamic systems, this exploratory study asked whether the properties of five CDST constructs manifest in the perceptions that plurilinguals have on their language development over time. Using qualitative data that examined language repertoires from a holistic view over a 3-month period, this study concludes that the constructs of attractor states, co-adaptation, phase shifts, and self-organization are identifiable in how plurilinguals perceive their changing repertoires. Evidence for emergence was not strong in our data; as discussed, the current theory around this construct could render it difficult to identify given our analytical approach. Alternatively, phenomena related to emergence could have been confounded with other CDST constructs (e.g.,

self-organization) and misidentified. Given the nascent nature of CDST's application to plurilingualism, we acknowledged that such conceptual limitations are likely to have occurred in this study.

On that note, both methodological and theoretical limitations need to be addressed. As for the former, methodological limitations include the short 3-month observation window and the limitations inherent in examining reported perceptions. Notably, we recognize that our study's design did not capture factors that were either imperceptible to our participants or unmarked (i.e., mundane). We do not view the small number of participants as a serious limitation. In this study, evidence for complex dynamics was unearthed thanks to an in-depth and personalized analysis that would be hindered by a greater number of participants.

As for theoretical limitations, we must first recognize that this study examined CDST constructs as they are hypothesized to apply to multi-/plurilingualism by theorists like Herdina and Jessner (2002) and Larsen-Freeman and Cameron (2008a). As such, the validity of this study's results should be weighed against critiques arguing that the foundational models that apply CDST to language (e.g., DMM by Herdina & Jessner, 2002) are insufficient given their ambiguity or inability to describe key constructs like state transitions (see Beisbart, 2021, for a more detailed overview).

In this way, a continued sharpening of the CDST model is one direction that future research should take, and such work is occurring (see Larsen-Freeman & Todeva, 2021). Further, engaging in deductive research like this study is another way forward. Deductive research, as opposed to inductive research, begins with a theory and then gathers data that either support or falsify hypotheses (de Bot & Larsen-Freeman, 2011). Deductively, this study shows that the concepts of attractor states, co-adaptation, self-organization, and phase shifts are readily observed in the perceptions that plurilinguals have of their changing repertoires, but emergence was not seen, perhaps because of conceptual limitations in what constitutes evidence. Therefore, this study acts as a reminder that CDST's application to plurilingualism is very promising, yet nascent. Crucial details still need to be worked out conceptually and then tested through research.

The above considered, does this study demonstrate that languages in a repertoire are complex dynamic systems? Yes, but with the caveat that future CDST models should advance a clearer conception of system dynamics. Does this study achieve its goal of problematizing the use of the linear model in research? Yes. Specifically, we observed phenomena that would defy observation in traditional study designs that use a snapshot conception of competency along linear scales (L1, L2, Ln). For example, our data show that the language systems of an individual each exhibit different levels of variability (see evidence for attractor states) and that this variability is not just moderated by a system's state of development (e.g., competence), but also by its fitness to context and the changing array of coexisting systems within the

same repertoire. Moreover, this variability (in terms of reported episodes of uncontrolled language interaction) seems tied to growth trajectories within a repertoire and language awareness (see evidence for co-adaptation).

Further, we saw how developmental jumps towards a higher function in one language can impact behaviour and skills in other languages. In a similar vein, we saw that spurts of developmental growth also concern the learning process itself evidenced by new rates of language learning within an environment (see evidence for phase shifts). Similarly, we saw that language systems can reach critical tipping points in which they gain a capacity to feed their own development, and this, without being directly forced by external influence (see evidence for self-organization).

Each of the above phenomena requires further substantiation, but the overall implication of this study is clear: the linear conception of repertoires (L_1 , L_2 , L_n) needs to be shelved so that the full nature of plurilingual development can be investigated. Studies that operationalize language learning based on end-point orders of acquisition are deficient in capturing the above phenomena and likely overlook them. Moreover, the generalizing tendencies of the linear model force much research to exclude most people from most studies in order to be considered valid. In the future, this should be turned on its head, especially if the goal of research is to elucidate universal language phenomena or patterns. By focusing on the individualized dynamics of language learning, this study shows that approaches like CDST can support researchers in designing methodologies that can include any individual in all their language glory.

Lastly, by engaging in a qualitative design, this study shows that concepts of CDST can be spoken about by people outside the realm of applied linguistics. Implicationally for education, this means that combining a plurilingual view with CDST's constructs can be a powerful metaphor that helps teachers and students conceive repertoires as a holistic phenomenon that unfurls across a state-space and whose development is individualized, dynamic and ongoing. As such, this study's findings support plurilingual frameworks for research and education (see Beacco et al., 2016; Council of Europe, 2001; 2020). Future work may be improved with a stronger synthesis between CDST and plurilingual theory in how language repertoires are conceived and subsequently treated in both the classroom and the laboratory.

Acknowledgement

We would like to sincerely thank the participants in this study as well as the anonymous reviewers and editors for their invaluable feedback, comments, and suggestions.

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