The Perceptual Attraction of Pre-Dominant Chords

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Among the three primary tonal functions described in modern theory textbooks, the pre-dominant has the highest number of representative chords. We posit that one unifying feature of the pre-dominant function is its attraction to V, and the experiment reported here investigates factors that may contribute to this perception. Participants were junior/senior music majors, freshman music majors, and people from the general population recruited on Prolific.co. In each trial, four Shepard-tone sounds in the key of C were presented: 1) the tonic note, 2) one of 31 different chords, 3) the dominant triad, and 4) the tonic note. Participants rated the strength of attraction between the second and third chords. Across all individuals, diatonic and chromatic pre-dominant chords were rated significantly higher than non-pre-dominant chords and bridge chords. Further, music theory training moderated this relationship, with individuals with more theory training rating pre-dominant chords as being more attracted to the dominant. A final data analysis modeled the role of empirical features of the chords preceding the V chord, finding that chords with roots moving to V down by fifth, chords with less acoustical roughness, and chords with more semitones adjacent to V were all significant predictors of attraction ratings.

Received: February 8, 2020, accepted April 3, 2021.

Key words: musical attraction, perception, pre-dominant, chord progression, harmony

"Harmonic function" is both a ubiquitous concept and one with varied meanings in the literature on Western tonal music (Harrison, 1994; Kopp, 1995; Nobile, 2016; Quinn & Mavromatis, 2011; Tymoczko, 2003; White, 2020a). It is also a mainstay of pedagogical practice: students learning about harmony ca. 1650–1900 (the "common-practice period") are taught that harmonic function refers to some combination of a chord's scale-degree content and its normative position, role, or behavior in a musical context. For instance, the authors of the open-source textbook Open Music Theory write, "Generally speaking, the function of a chord concerns the notes that belong to it (its *internal characteristics*), the chords that tend to precede and follow it, and where it tends to be employed in the course of a musical phrase" (Shaffer, Hughes, & Moseley, 2014, emphasis in original).

Several popular and current North American theory textbooks take the further step of grouping together chords with similar functions into three distinct categories: tonic (T), dominant (D), and pre-dominant (PD) (Caplin, 1998, 2013; Gauldin, 2004; Kostka & Payne, 2009; Laitz, 2008; Laitz & Bartlette, 2010; Marvin & Clendinning, 2016; Shaffer et al., 2014; Snodgrass, 2015). Moreover, these same textbook authors posit that harmonic functions are employed in the paradigmatic succession T–PD–D(–T), and prescribe standard orderings for chords within the pre-dominant region (described further below).

As a pedagogical heuristic, the pre-dominant is of particular interest. Due to the large number of chords it encompasses, its "internal characteristics," and by extension its perceptual features, are difficult to generalize. Caplin (2013, pp. 1–2) offers a typical classification of the three functions, which highlights the disparity in chordal membership among them:

1. Tonic harmonies include the I and VI chords in their various positions.
2. Dominant harmonies include the V and VII chords in their various positions. III can function as a dominant substitute in some contexts (as in the progression V–III–VI).
3. Pre-dominant harmonies include a wide variety of chords: IV, II, ♭II, secondary (applied) dominants of the dominant (such as VII^7/V), and the various "augmented-sixth" chords.

Thus, the pre-dominant function cannot be generalized by chord quality: it includes major, minor, and

Music Perception, volume 39, issue 1, pp. 21–40, issn 0730-7829, electronic issn 1533-8312. DOI: https://doi.org/10.1525/mp.2021.39.1.21

diminished triads; seventh chords; non-tertian chords; and diatonic and chromatic sonorities. Nor can it be generalized by scale degrees; for instance, some chords have a root of $\hat{2}$, others have a root of $\hat{4}$, and some, the augmented sixth chords, arguably do not have a root at all (Harrison, 1995, pp. 171–172, n. 3).

In one of the first theoretical discussions of the pre-dominant concept, Guck (1978) observes that "no one chord is particularly characteristic of P[D]" (p. 37), and this reflects Forte's (1962) early conception of "dominant preparation" as encompassing a variety of chords. Caplin (1998), too, defines the pre-dominant function as "various harmonies whose primary role is to progress to a dominant" (p. 256), in contrast to tonic and dominant functions, which are closely associated with I and V chords (p. 23). Recently, Nobile (2016) has asserted further that the primary attribute of the pre-dominant function, unlike tonic and dominant functions, is its *syntactical* role in a harmonic progression; that is, any chord can be a pre-dominant chord if it follows a tonic chord and precedes a dominant chord and is different from either. With this in mind, we note that many textbooks contain a similar syntactical notion of pre-dominant function despite using other terms like "intermediate harmonies" (Aldwell & Schachter, 2003), "dominant preparation" (Forte, 1962), and "subdominant function" (Burstein & Straus, 2016). Moreover, we observe that along with its syntactical position, the pre-dominant function is often described as seemingly drawn or attracted to the dominant; we discuss this further below. This study tests the factors that contribute to this perception.

Chord Categories and the Pre-Dominant Function

Textbook authors take a further step in forming two subcategories of pre-dominant harmonies: diatonic and chromatic. In textbook accounts, diatonic IV and ii triads (and, in some cases, their seventh chords) are the next chords introduced after I and V (Aldwell & Schachter, 2003; Burstein & Straus, 2016; Caplin, 1998, 2013; Forte, 1962; Gauldin, 2004; Kostka & Payne, 2009; Laitz, 2008; Snodgrass, 2015). In turn, students in their first year of a music theory curriculum encounter these chords as first examples of the pre-dominant function.

Some authors explicitly attribute the primacy of IV and ii within the pre-dominant function to their particular *scale-degrees*. Gauldin (2004), for instance, writes, "the most active scale degree in the pre-dominant family (IV, ii, and their seventh chords) is $\hat{6}$ . . . The other scale step these harmonies have in common [is] $\hat{4}$" (p. 95), while Burstein and Straus (2016) note: "IV, ii^6, and ii^6_5 all . . . use $\hat{4}$ in the bass, share most of the same notes, and function similarly. . . . [Each] harmony [also] contains $\hat{6}$" (p. 146). Insofar as these authors place an emphasis on shared scale degrees $\hat{4}$ and $\hat{6}$, their explanations bear resemblance to a historical notion of tonal function introduced by Hugo Riemann (1893). In Riemann's theory, the function of a chord is determined not by syntax or chord succession but by its pitch-class content and its relation to the tonic (Hyer, 2011, pp. 108–109). Every chord in a key can be understood as one of three functions—tonic (T), dominant (D), and subdominant (SD)—or a transformation thereof, with the triads, I, V, and IV, as functional representatives or prototypes (Agmon, 1995; Bernstein, 2002; Harrison, 1994). Modern textbook authors who employ the term "subdominant," and even some who don't, retain this sense of pitch-class kinship (IV and ii share similar pitch classes) but they do so within a function-as-syntax framework (IV and ii progress to V). (See White and Quinn, 2018, for a useful discussion on the historical use of the terms "subdominant" and "pre-dominant" and their adoption in recent music theory.) Hence scale-degrees $\hat{4}$ and $\hat{6}$ may convey "pre-dominantness" for listeners with formal education in diatonic harmony (undergraduate music students).

Chromatic pre-dominant chords are introduced in later chapters of most harmony textbooks (e.g., Kostka & Payne, 2009, Laitz, 2008, Marvin & Clendinning, 2016), and likewise, undergraduate students learn them in the second semester or second year of the multi-semester theory sequence. Chromatic chords functioning as pre-dominants include secondary dominants (i.e., applied chords) to V, augmented sixth chords, and the Neapolitan sixth chord. Again, some theorists emphasize their kinship to each other and to the diatonic pre-dominants by underscoring the presence of scale-degrees $\hat{4}$ and $\hat{6}$ and their chromatic variants $\sharp\hat{4}$ and $\flat\hat{6}$ (Caplin, 1998); Laitz, for instance, describes the augmented sixth chords as a chromatic variant of the Phrygian cadence (iv^6–V), where $\hat{4}$–5 in the Phrygian cadence is replaced by $\sharp\hat{4}$–5 (2008, pp. 678–679). (Harrison, too, remarks on the "stronger spice" that $\flat\hat{6}$ has in comparison to the "gentle and soft Subdominant flavor" of $\hat{6}$, p. 118). Textbooks also prescribe a specific order for the two pre-dominant subcategories, such that the original T–PD–D(–T) paradigm could be refined further: T–PD(diatonic)–PD(chromatic)–D(–T). For example, Laitz (2008, pp. 686–687) discusses Beethoven's Piano Sonata No. 13 (Op. 17, No. 1, mm. 28–29) where a diatonic iv^6 moves to a German augmented sixth chord (similar examples can be found on pp. 688–689).

Finally, some textbook authors posit another subcategory of chords that have a "bridging" function between tonic and pre-dominant functions, or a "pre-pre-dominant" function (Laitz, 2008, p. 446; also Laitz & Bartlette, 2010; Kostka & Payne, 2009; Marvin & Clendinning, 2016); Dimitri Tymoczko adopts a similar stance from a speculative perspective (2003, p. 7). Bridge chords include vi, iii, and their seventh chords. With them, the paradigmatic succession of functions is extended further: T–Bridge–PD(diatonic)–PD(chromatic)–D(–T). Experimental stimuli in the present study contained chords belonging to the categories described in textbook accounts (diatonic and chromatic pre-dominants, bridge chords) and to a fourth category of "non-pre-dominants" containing tonic and dominant-substitute chords; see Table 1.

Pedagogical Descriptions of Pre-Dominant Chord Successions

In describing the succession of chords and chord functions, many textbook authors take the position that our understanding of chord syntax can be understood from statistical regularities in a corpus of music (Burstein & Straus, 2016; Forte, 1979; Gauldin, 2004; Kostka & Payne, 2009; Piston & deVoto, 1978). Kostka and Payne, for instance, provide the diagram of chord successions shown in Figure 1. They write, "Most often, IV has a pre-dominant function, moving directly to V or vii^{o}, or it may expand the pre-dominant area by moving first to ii or ii^{6}" (2009, p. 111); the arrow from IV down to ii indicates that IV can go to ii, but the ii chord does not go to IV. Some textbook authors, however, go beyond simply describing frequency, employing metaphorical language to invoke felt experience (Aldwell & Schachter, 2003; Benward & White 1993; Laitz, 2008; Marvin & Clendinning, 2016; and Snodgrass, 2015). Benward and White (1993), for instance, suggest that ii–V occurs more often than V–ii because the former provides more "direction and thrust" toward the tonic (p. 198), and Aldwell and Schachter (2003) note that IV, ii, "and their derivatives" are "particularly well suited to *lead into and intensify dominant harmony*" (p. 126, emphasis in original).

Similar metaphorical language is also used to describe the ordering of harmonies within the pre-dominant function itself. Laitz (2008), writes, "Given that two of its voices [those with $\flat\hat{6}$ and $\sharp\hat{4}$] are so *goal-directed* toward $\hat{5}$, the augmented sixth chord is usually the last event before the dominant, following either iv$^{(6)}$ or VI" (p. 686, emphasis added). Similarly, Marvin and Clendinning (2016) discuss the specific ordering of the three types of augmented sixth chords: "Occasionally, composers will write all three types [of augmented 6th chords] in quick succession *to intensify motion* to the dominant at a cadence—usually in the order Italian, French, German" (p. 560, emphasis added). In all of these descriptions, there is a sense that musical events (scale degrees, chords) are drawn or pulled to each other, possessing varying degrees of *attraction* to one another and to the goal of the dominant harmony.

Notably, textbooks sometimes offer competing reasons for the proper ordering of chords. For instance, when justifying why ii "is the most common pre-dominant chord," Laitz states, "1. The progression ii–V proceeds by descending-fifth (or ascending-fourth) motion, the strongest root motion in tonal music. 2. The supertonic introduces a striking sonority and modal contrast in progressions [. . .]. 3. The progression ii–V–I is often set to $\hat{2}$–$\hat{7}$–$\hat{1}$ in the soprano, versus the *less dynamic* $\hat{1}$–$\hat{7}$–$\hat{1}$ when IV functions as the pre-dominant" (2008, p. 283, emphasis added). Thus, certain acoustic and scale-degree features may also be predictors of attraction; further below, we propose five such features (see "Five possible features of pre-dominant chords").

Modeling Musical Forces

The notion that musical events are experienced in terms of musical forces can be found in discourse about music since antiquity (see Rothfarb, 2002, and Larson, 2012, for overviews). Indeed, Larson and VanHandel (2005) write, "Musicians have long talked about the tendency of certain notes to attract other notes, and they have often used metaphors (such as attraction, gravity, magnetism, pulling, yearning, and 'leading tone') to describe those dynamic tendencies" (p. 123). Models of melodic attraction have been offered by Bharucha (1996), Margulis (2005), and Larson and VanHandel (2005). Further, Larson and VanHandel (2005) conducted an experimental study to investigate listeners' judgments of dynamic tendencies within melodic patterns, asking participants to rate how well the second note of a three-note melody "led" to the third note. They posited that three forces, "gravity," "magnetism," and "inertia," would govern the pull from one note to another, and they found partial support for their hypotheses. Their concept of magnetism, "the tendency of [tonally] unstable notes to move to the closest stable pitch" (p. 119), is similar to the notion of attraction that theorists have invoked for harmonic functions, that is, that there is a magnetic pull from a less stable pre-dominant chord to a more stable dominant chord.

TABLE 1. ***Features of the 31 Chords Heard Prior to the Dominant Chord in the Present Experiment***

Chord Category	Chord	Chord Roughness (Parncutt, 1989)	Semitonal Adjacency to V (number of scale-degrees in the chord that can move by semitone to a scale-degree in V)	Descending-Fifths Root Motion (1: whether $\hat{2}$ or $\flat\hat{2}$ is the root)	Chord Distance (Lerdahl, 2001)	Number of $\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, and/or $\hat{6}$ in the chord
Chromatic Pre-Dominant Chords	N^6: D♭-F-A♭	0.1013	2	0	7	2
	It^6: A♭-C-F♯	0.1745	3	0	7	2
	Fr^6: A♭-C-D-F♯	0.261	3	0	6	2
	Ger^6: A♭-C-E♭-F♯	0.2321	4	0	7	2
	V/V: D-F♯-A	0.1017	1	1	8	2
	V^7/V: D-F♯-A-C	0.2325	2	1	8	2
	vii^o/V: F♯-A-C	0.1322	2	0	9	2
	vii^{o7}/V: F♯-A-C-E♭	0.1977	3	0	9	2
Diatonic Pre-Dominant Chords	ii: D-F-A	0.1014	0	1	5	2
	ii^o: D-F-A♭	0.131	1	1	5	2
	ii^7: D-F-A-C	0.2348	1	1	5	2
	$ii^{ø7}$: D-F-A♭-C	0.2313	2	1	5	2
	IV: F-A-C	0.1016	1	0	8	2
	iv: F-A♭-C	0.1012	2	0	8	2
	IV^7: F-A-C-E	0.3041	1	0	8	2
	iv^7: F-A♭-C-E♭	0.2347	3	0	8	2
Bridge Chords	iii: E-G-B	0.101	0	0	7	0
	III: E♭-G-B♭	0.102	2	0	8	0
	iii^7: E-G-B-D	0.2345	0	0	6	0
	III^7: E♭-G-B♭-D	0.3046	2	0	7	0
	vi: A-C-E	0.1012	0	0	8	1
	VI: A♭-C-E♭	0.1014	2	0	8	1
	vi^7: A-C-E-G	0.235	1	0	7	1
	VI^7: A♭-C-E♭-G	0.3045	3	0	7	1
Non-Pre-Dominant Chords	I: C-E-G	0.1009	1	0	5	0
	i: C-E♭-G	0.1016	2	0	5	0

(continued)

TABLE 1. *(continued)*

Chord Category	Chord	Chord Roughness (Parncutt, 1989)	Semitonal Adjacency to V (number of scale-degrees in the chord that can move by semitone to a scale-degree in V)	Descending-Fifths Root Motion (1: whether $\hat{2}$ or $\flat\hat{2}$ is the root)	Chord Distance (Lerdahl, 2001)	Number of $\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, and/or $\hat{6}$ in the chord
	I^7: C-E-G-B	0.3038	1	0	4	0
	i^7: C-E♭-G-B♭	0.2355	3	0	5	0
	vii^o: B-D-F	0.1315	0	0	3	1
	vii^{ø7}: B-D-F-A	0.2326	0	0	3	2
	vii^{o7}: B-D-F-A♭	0.1975	1	0	3	2

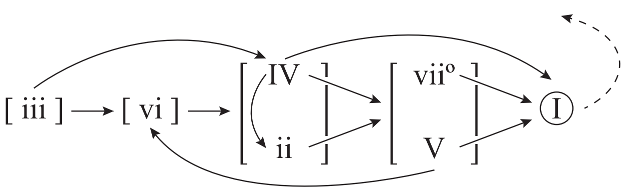

FIGURE 1. Diagram of common chord progressions in the major mode, as illustrated by Kostka and Payne (2009, p. 111).

Research on the perception of chord-to-chord successions (the harmonic domain) has largely focused on the experience of tension. Lerdahl's (2001) theory of tonal tension (Bigand & Parncutt, 1999; Bigand, Parncutt, & Lerdahl, 1996; Krumhansl, 1996; Lerdahl & Krumhansl, 2007; Vega, 2003) and Krumhansl's (1990) tonal hierarchy values (Bigand et al., 1996; Schmuckler, 1989) have been shown to be reliable metrics for predicting chordal tension. Some of these experiments have found that music training plays a role in tension judgments (Bigand et al., 1996), whereas others find that responses were uniform across participants with differing musical backgrounds (Krumhansl, 1996). Notably, previous studies of harmonic tension have either taken a case-study approach, collecting chord-to-chord tension ratings in single compositions (Krumhansl, 1996; Schmuckler 1989; Vega, 2003), or tested the relative tension of individual chords only in relation to a governing tonic chord (Bigand et al., 1996). Our study, in contrast, focuses on the perceived relationship between chords with the syntactic functions pre-dominant and dominant.

In our experiment, we employ the metaphor of "attraction" rather than "tension" in discussing two chordal functions in time, a choice motivated by textbook descriptions of the phenomenon and by our experimental procedure below. We acknowledge, however, that attraction and tension are interrelated. From a theoretical perspective, Lerdahl (1996) posits that "all attractions are from less stable to more stable events," and his attractional analyses of melodic lines always describe *decreases* in tension (see p. 353); this view is also held by Larson and VanHandel (2005), as noted above. Our experiment does not test the perceptual validity of this claim (for instance, that pre-dominant chords are "more tense" than dominant chords). Future research could certainly investigate the relationship between these two metaphors in the context of chord-to-chord successions, although "tension" itself has various competing theories to describe it (e.g., Farbood, 2012; Harrison & Pearce, 2020; Navarro-Caceres, Caetano, Bernardes, Sanchez-Barba, & Sanchez-Jara, 2020; Pressnitzer, McAdams, Winsberg, & Fineberg, 2000; Teo, 2020).

Pre-Dominant Chord Attraction: Three Questions

The present study investigates the perceptual validity of theoretical descriptions of the pre-dominant function. Our three overarching questions include:

1. Are textbook orderings of pre-dominant chords perceptually supported?
2. What role does music training, and specifically music theory training, play in perceptions of pre-dominant chords?
3. What features of the chords themselves (i.e., internal characteristics) contribute to perceptual differences among chords?

In each trial of the experiment, participants heard four Shepard-tone sounds in the key of C in this order: Sound 1 was the tonic note, Sound 2 was one of 31 different chords (Table 1), Sound 3 was the dominant triad, and Sound 4 was the tonic note. Participants rated the attraction of Sound 2 to Sound 3. We considered, but ultimately rejected, some alternative terms to "attraction" that are often found in the music cognition literature: "tension" (e.g., "how tense is Sound 2?") might have encouraged participants to pay attention only to the pre-dominant chord and judge how well it fits in the overall key, while "expectation" (e.g., "how expected is Sound 3?") might have confused participants, since Sound 3 was V in all trials. (In this way, our conception of attraction differs from that found in Vega (2003): "the measure of how strongly [participants] perceived the second chord as an expected consequence of the first chord in the chord pair" (p. 41); in Vega's study, the second chord in a chord pair changed on each trial, but in our experiment, it was always V.) We predicted that the chromatic pre-dominants shown in Table 1 would be perceived as the most attracted to the dominant, followed by diatonic pre-dominants, bridge chords, and finally non-pre-dominant chords, and that this differentiation would be more pronounced as training in Classical music, and particularly in music theory, increased. This ranked ordering reflects the degree to which each chord category would be theorized to be attracted to the dominant according to the literature (see theoretical accounts under "Pedagogical Descriptions of Pre-Dominant Attraction").

We investigated our three overarching questions by modeling our data using a series of regression models. The goal of our analysis was to investigate the extent to which claims from the music-theoretic literature aligned with perceptual data on ratings of attraction. In order to investigate our first research question, we estimate the extent that top-down chord categories found in music theory textbooks, as described above, were predictive of attraction ratings. Our second analysis extends this model by accounting for music theory training in addition to the top-down categories. That is, because listeners may need declarative knowledge about categories of pre-dominants to be able to judge relative attraction, we used participants from three groups to capture a wide range of music theory training, which was a factor in other similar studies (e.g., Arthurs, Beeston, & Timmers, 2018; Bigand et al., 1996). Following this, we investigate the extent to which internal features of the chords are able to predict attraction, modeling the five features listed below; in so doing, we complement our top-down approach with a bottom-up study, formalizing a hypothesis that internal characteristics of chords also relate to attraction (Shaffer et al., 2014) and that this might relate to an individual's music training.

Mirroring our above strategy to take both a bottom-up and top-down approach to our perceptual data using supervised methods, we also employ a top-down and bottom-up analysis using unsupervised methods (James, Witten, Hastie, & Tibshirani, 2013). We first decompose the empirical response data from our experiment using principal component analysis (PCA); this analysis serves as our top-down method of understanding listener response strategies. Second, we submit the features used in our feature-based regression model to a hierarchical agglomerative clustering algorithm to consider novel ways chord categories might be re-conceptualized. Our choice to incorporate unsupervised methods follows recent literature that has been successful in helping understand complex musical structures such as chord progressions (White & Quinn, 2018) and tonality (Albrecht & Huron 2014; Moss, 2019; White, 2014).

Five Possible Features of Pre-dominant Chords

We investigated the extent to which the following chord features predict pre-dominant attraction ratings:

1) ***Presence of scale degrees $\hat{4}$, ♯$\hat{4}$, ♭$\hat{6}$, $\hat{6}$:*** As noted above, several textbook authors attribute the primacy of certain pre-dominant harmonies (in particular, IV, ii, and the augmented sixth chords) to their scale degrees. Other music theorists have similarly maintained that scale-degree membership is the basis of chordal function (e.g., Harrison, 1994) and investigated scale-degree content in relation to harmonic function (Tymoczko, 2003; White & Quinn, 2018). With this research in mind, we hypothesized that chords containing scale degrees a whole step or half step away from $\hat{5}$ would be perceived as more attracted to V. We counted how many of scale-degrees $\hat{4}$, ♯$\hat{4}$, ♭$\hat{6}$, and $\hat{6}$, occurred in each chord, hypothesizing that higher numbers of these scale degrees would result in higher attraction ratings. Across the 31 chords rated in this experiment, values for this chord feature were 0, 1, or 2. Table 1 displays the full list of features of chords and their computationally derived features. Scale degrees $\hat{1}$ and $\hat{2}$ were not included in this feature, because they are not a step away from $\hat{5}$. Further, Harrison (1994) contends that $\hat{1}$ in IV, for example, has little independent functional power (p. 55); $\hat{2}$ in ii is described similarly, such that $\hat{2}$ "dilutes the

otherwise pure Subdominantness" of $\hat{4}$ and $\hat{6}$ (p. 60).

2) ***Semitonal adjacency to V:*** A variety of methods have been applied to calculating the voice-leading connection between two chords, such as the melodic attraction model found in Lerdahl (2001) and the "taxicab metric" used by Bigand et al. (1996) and Rogers and Callender (2006), the latter of which is the sum of motion (in semitones) between voices within two chords. Lerdahl's melodic attraction model starts with the assumption of either major or minor tonality, one that we purposely do not make in this experiment (we used a single tonic note to establish the key, rather than a major or minor tonic chord). Moreover, Vega (2003) found that counting up semitonal motion between two chords correlated with listener perceptions of attraction better than Lerdahl's melodic attraction model. Rogers and Callender (2006) tested the effect of voice-leading distance between two Shepard-tone trichords on their perceived distance, finding that higher values in the total sum of motion led to participants perceiving a sense of greater distance between two chords. It may be that this perceived distance also contributes to attraction ratings.

   Both Lerdahl's melodic attraction model and the taxicab metric were unsuitable for our purposes, because some of our Chord 2 harmonies were Shepard-tone seventh chords moving to a Shepard-tone V triad; thus we would only be able to make hypothetical voice-leading calculations based on a variety of assumptions about chord doubling, inversion, and spacing. Instead, we use a voice-leading metric that calculates the number of scale degrees in the pre-dominant chord that *can* move by one semitone when resolving to V. For instance, all four scale-degrees in the Ger^6 chord can move by semitone to V: $\flat\hat{6}$ to $\hat{5}$, $\hat{1}$ to $\hat{7}$, $\flat\hat{3}$ to $\hat{2}$, and $\sharp\hat{4}$ to $\hat{5}$. Thus, since we use Shepard tones, we count the number of pitch classes in a chord that are one semitone away from pitch classes of the V chord, acknowledging that there is no actual pitch-based voice leading at all. Values for semitonal adjacency to V ranged from 0 to 4 across all 31 trials heard in the experiment (Table 1). Following textbook descriptions, we hypothesized that semitonal adjacency to V would be a source of "goal-directed motion" (Laitz, 2008, p. 686), such that the higher the number of voices moving by semitone, the higher the perceived attraction.

3) ***Chord roughness:*** Bigand et al. (1996) found a weak but positive correlation between acoustic roughness and musicians' ratings of chordal tension. The roughness of a chord may contribute similarly to the perception of chordal attraction. Chord roughness values were determined using Richard Parncutt's (1989) adaptation of Hutchinson and Knopoff's model (1978), which can be applied to pure, complex, or Shepard tones. Roughness values for the 31 chords rated in our study ranged from 0.1009 for the tonic chord (CM) chord to 0.3046 for $\flat$III^7 (E$\flat$M^7). Roughness values for all trials can be found in Table 1. We used roughness rather than a measure of chordal dissonance (such as whether a chord contains a seventh), because the former is a continuous variable and the latter a binary variable. We acknowledge that sensory roughness is different from musical dissonance, while also noting that chords with higher acoustic roughness values do tend to contain dissonances like chordal sevenths. In music theory textbooks, chordal dissonance is described as an unstable event leading to more stable resolution (e.g., Laitz writes, "Just as dissonant intervals resolve to consonant ones, dissonant chords are active sonorities that seek resolution and, in so doing, create tension and heighten expectation in tonal music," 2008, p. 213). Thus, we hypothesize that chord roughness, too, will contribute to higher attraction ratings.

4) ***Chord distance:*** Lerdahl's chord distance calculation (2001, p. 60) has been found to positively correlate with listener judgements of tension between two chords (Bigand et al., 1996; Krumhansl, 1996; Lerdahl & Krumhansl, 2007; Vega, 2003). We hypothesize that Lerdahl's chord distance could play a similar role in the perception of pre-dominant attraction, where chords further away from the dominant are more attracted to it. Lerdahl's chord distance formula, which takes into account the relationship between two chords as well as the overall key, was calculated between each chord and its resolution to the dominant triad; values for this chord distance can be found in Table 1.

5) ***Descending-fifths root motion:*** Root motion by descending fifths (in major: I–IV–vii^{o}–iii–vi–ii–V–I) has long been considered paradigmatic in tonal music (Rameau, 1722/1971; Schoenberg, 1954/1969), perhaps due to its frequency (e.g., see Tymoczko, 2003, and Quinn & Mavromatis, 2011, for evidence that descending-fifths motions are the most frequent root motions in Bach chorales).

Authors of theory textbooks have likewise attributed a sense of forward momentum to this progression; for example, Benward and White (1993) write, "Undoubtedly, the most common and the strongest of all harmonic progressions is the *circle progression*—adjacent roots in ascending fourth or descending fifth relationship . . . The circle progression, like no other, provides direction and drive toward a goal—toward the completion of momentum, from tension to relaxation" (p. 198). Similarly, Kostka and Payne (2009) write the following when introducing the circle-of-fifths progression in their textbook: "Why is it that some chord successions seem to 'progress,' to move forward toward a goal, whereas others tend to wander, to leave our expectations unfulfilled?" (p. 103). And as mentioned above, Laitz's first explanation for why "the supertonic is the most common pre-dominant chord" and "why composers consider the supertonic to be an effective pre-dominant" is due to the fact that "the progression ii–V proceeds by descending-fifth (or ascending-fourth) motion, the strongest root motion in tonal music" (2008, p. 283).

To test the hypothesis that chords adjacent to V by descending-fifths root motion are more attracted to V than other chords, we coded this chord feature as a categorical variable in Table 1 (Cohen & Cohen, 1983): if the root of the chordal stimulus is $\hat{2}$ or ♭$\hat{2}$, we entered "1" in the table; if not, we entered "0." Note that chords built on $\hat{2}$ *and* ♭$\hat{2}$ were included in this hypothesis, as it is common for the ♭II chord to be included within minor-mode descending-fifths progressions as a variant of ii°. For example, Kostka and Payne (2009, p. 386) describe how ♭II can be found in root position within the circle-of-fifths progression iv–VII–III–VI–♭II–V–i and illustrate with examples from Chopin to Verdi to Lionel Ritchie's "Hello." Note that the chord distance feature (item 4, above) calculates progressions and retrogressions on the circle of fifths in the same way, that is, I to V (and V to I) is the same distance as ii to V (Lerdahl, 2001, p. 145). This feature, in contrast, distinguishes between the two directions along the circle and only includes descending-by-fifths root motion.

Method

The following experiment was approved by the Homewood Institutional Review Board of the Johns Hopkins University (#HIRB00009746). All data and analyses can be found on the OSF framework (https://osf.io/9fbcs/).

PARTICIPANTS

Participants ($N = 59$) were recruited in introductory ear-training courses at the Peabody Conservatory at the Johns Hopkins University and through the online platform Prolific (www.prolific.co). Freshman music majors at Peabody ($n = 21$) were learning diatonic harmony at the time of the experiment and took the experiment early in the fall semester. Their mean age was 18.29 ($SD = .90$). Junior/Senior music majors at Peabody ($n = 18$) had completed at least four semesters of diatonic and chromatic music theory and aural skills courses, and their mean age was 20.11 ($SD = .90$). Participants who took the experiment on Prolific ($n = 20$) were prescreened to share demographic characteristics with students at the Peabody Conservatory, but their level of musical involvement was more reflective of a general population. That is, they were enrolled in an undergraduate program, were living in the United States, were English speaking, and 18–23 years old ($M = 20.80$, $SD = 1.91$).

At the end of the experiment, participants completed the full self-report questionnaire from the Goldsmiths Musical Sophistication Index (Gold-MSI), v1.0 (Müllensiefen, Gingras, Musil, & Stewart, 2014). Participants' music theory training, as measured by question 38 on the Gold-MSI, ranged from $M = 5.17$ ($SD = 0.96$) for junior/senior music majors, $M = 3.62$ ($SD = 1.88$) for freshman music majors, and $M = 2.25$ ($SD = 1.74$) for Prolific participants. Between-group differences in music theory training are visualized in Figure 2B.

MATERIALS

In each of the 31 trials, participants heard four Shepard-tone sounds in the key of C in this order: Sound 1 was the tonic note, Sound 2 was one of 31 different chords (Table 1), Sound 3 was the dominant triad, and Sound 4 was the tonic note. We chose to present only a tonic note (rather than a triad) for Sound 1 and Sound 4, so as to not invoke the major or minor mode. The 31 chords heard as Sound 2 were organized into four groups, as shown in Table 1: 1) chromatic pre-dominants, which are secondary chords of V, augmented sixth chords, and the Neapolitan chord; 2) diatonic pre-dominants, which are subdominant and supertonic harmonies in major and minor keys; 3) bridge chords, which are mediant and submediant harmonies; and 4) triads and seventh chords that are not pre-dominants (the tonic and leading-tone chords).

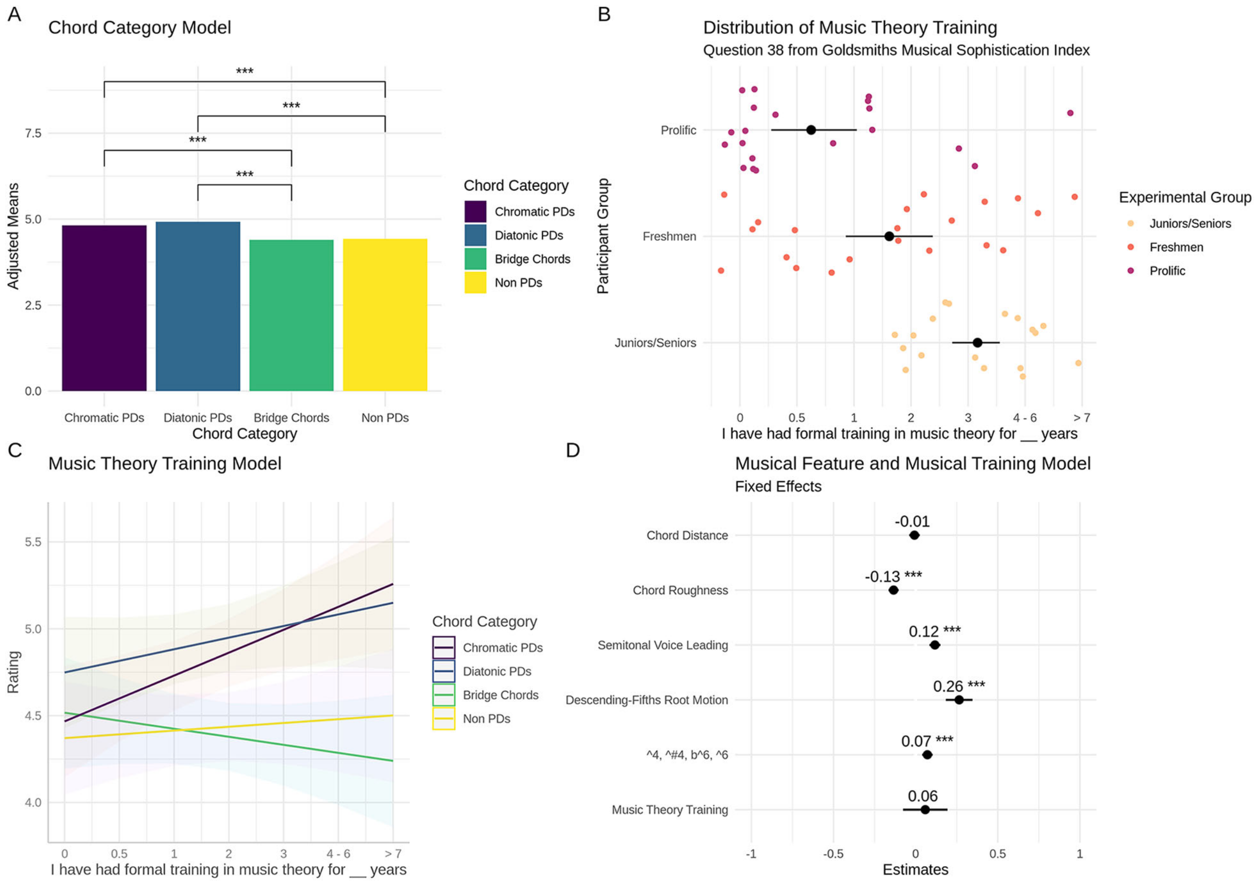

FIGURE 2. Regression analyses.

Shepard tones (Shepard, 1964) spanning ten octaves were used to minimize possible effects of register, contour, and chordal inversion (e.g., Lahdelma & Eerola, 2016a, 2016b, found that participants perceived an increase in energy and tension from root position chords through first inversion to second inversion; Roberts & Shaw, 1984, also found that participants responded differently when hearing triads in root versus first inversion). Individual events were first created in Max/MSP (v7.3.4, https://cycling74.com/) and recorded using Audio Hijack (v3.5.6, https://rogueamoeba.com/audiohijack/). The recorded events were organized into progressions using Logic (v10.4.6, https://www.apple.com/ca/logic-pro/), and these progressions were exported to create separate MP3 files for each trial. Each progression was seven seconds long.

PROCEDURE

The experimental interface was created using the Qualtrics survey website (www.qualtrics.com) and administered through an internet browser. Participants took the experiment individually, each using their own computer or tablet, and they were instructed to use headphones; a sample Shepard tone on the landing page offered participants the opportunity to adjust their headphones to a comfortable volume level. Participants at the Peabody Conservatory took the experiment in a quiet classroom, and participants on Prolific were asked to complete the experiment in a quiet location.

Participants were told that on each trial, they would hear a "series of four sounds" that would automatically play two times. Their task was to answer the question: "How attracted is Sound 2 to Sound 3?" using a continuous sliding scale from 1 (*not at all attracted*) to 7 (*extremely attracted*). They were told to think of "attraction" as "a magnetic pull from Sound 2 to Sound 3."

In each trial, participants clicked a button to play the chord progression once; the progression repeated automatically after five seconds, for a total of two hearings. Participants were required to respond to the question that assessed attraction ratings before moving on to the next trial but could take as much time as they needed to do so. Each participant heard all 31 trials in randomized order (Block 1) and then heard all trials again in a different randomized order (Block 2), for a total of 62 trials. Following these trials, participants took the full self-report questionnaire from the Gold-MSI. The entire experiment lasted 25–35 minutes.

Results

In order to model our data, we fit a regression model corresponding to each of our three overarching research questions (see "Pre-Dominant Chord Attraction: Three Questions"). In all models, the dependent variable was the rating of attraction made by participants. In order to avoid violating the assumption of independence, we averaged across the two experimental blocks, yielding a single rating of attraction per participant, per chord. Before collapsing across experimental conditions, we computed the RKF, the reliability of average of all ratings across all items and time points, to be 0.96 (Shrout & Lane, 2012) using the psych package in R (Revelle, 2019) and deemed the two conditions to be similar enough to be modeled as one.

An additional set of analyses was also run that did not collapse across ratings, utilizing hierarchical, mixed effects modeling. This set of analyses can be found in our supplemental material. The pattern of findings between these sets of analyses was nearly identical, suggesting the findings are robust to choice of analysis. All statistical analyses were run using either base R or the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in the R programming language (R Core Team, 2020). All parameter estimates are presented in Table 2. All regression coefficients are presented as unstandardized unless otherwise noted.

MODELING

Chord Category Model

In order to model data from our first question ("Are textbook orderings of pre-dominant chords perceptually supported?"), we ran a repeated measures ANOVA specified as a linear mixed effect model, modeling chord category as a fixed effect and participant as a random effect. Following a significant omnibus test $F(3, 3596) = 54.87$, $p < .001$, $R^2_{\text{conditional}} = .310$ we ran a Tukey post hoc comparison of group means using the multcomp package in R (Hothorn, Bretz, & Westfall, 2008). Results from this comparison found significant differences between all pairs ($p < .001$) except between non-predominant and bridge chords as well as between diatonic pre-dominant and chromatic pre-dominant chords. This result is visualized in Figure 2A.

Musical Theory Training Model

To model data from our second hypothesis ("What role does music training, and specifically music theory training, play in perceptions of pre-dominant chords?"), we fit a second repeated measures ANOVA specified as a linear mixed effects model similar to the chord category model, but now adding a measure of music theory training as measured by question 38 on the Gold-MSI as a fixed effect, including an interaction between music training and chord category. Results from the statistical test revealed a significant interaction between chord category and music theory training $F(3, 3593) = 17.05$, $p < .001$, a significant main effect of chord category $F(3, 3593) = 4.98$, $p < .001$, and no significant effect of music theory training $F(1, 57) = 0.85$, $p > .05$ with $R^2_{\text{conditional}}$. We additionally plot the model predictions from this model in Figure 2C in order to visualize the significant interaction effect.

Comparing the chord category model to the music theory training model, the addition of the music theory training resulted in a significant increase of model fit $\chi 2(4) = 55.77$, $p < .001$. Relative fit indices between the chord category model (AIC = 11,261, BIC = 11,299) also improved with the music theory training model (AIC = 11,218, BIC 11,280).

Chord Features Model

To model data investigating our third question ("What features of the chords themselves contribute to perceptual differences among chords?"), we fit a linear mixed effects model to our data that incorporated the five features as well as musical theory training. Here, we used Presence of Scale Degrees ($\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, $\hat{6}$), Semitonal Adjacency to V, Chord Roughness, Chord Distance, Descending-Fifths Root Motion, and music theory training as fixed effects with participant modeled as a random effect. The coefficient estimates for each chord category are plotted in Figure 2D and reflect standardized regression coefficients presented with estimations of statistical significance from the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017).

Unsupervised Learning Models

To better understand response strategies used by participants, we modeled the behavioral responses from our experiment using a principal component analysis (PCA). To consider other ways that the traditional chord categories might be re-conceptualized, we submitted the five features of our model to a hierarchical agglomerative clustering algorithm.

Principal Component Analysis. In order to perform our principal component analysis, we decomposed the ratings of each of our chords found in Table 1 ($N = 31$)

TABLE 2. *Mixed Effects Model Estimates*

	Chord Category Model			Music Theory x Chord Model			Chord Feature Model		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
Bridge Chords	4.40	[4.20 – 4.59]	< **.001**	4.56	4.16 – 4.97	< **.001**	-0.04	-0.14 – 0.07	.522
Chromatic PDs	0.42	[0.32 – 0.52]	< **.001**	-0.23	-0.44 – -0.02	**.031**			
Diatonic PDs	0.53	[0.43 – 0.63]	< **.001**	0.12	-0.09 – 0.33	.262			
Non PDs	0.03	[-0.07 – 0.13]	.536	-0.21	-0.43 – 0.00	.05			
Music Theory Training				-0.05	-0.14 – 0.05	**.354**			
Chromatic PDs x Music Theory Training				0.18	0.13 – 0.23	< **.001**			
Diatonic PDs x Music Theory Training				0.11	0.06 – 0.16	< **.001**			
Non PDs x Music Theory Training				0.07	0.02 – 0.12	**.01**			
Chord Distance							-0.01	-0.04 – 0.02	.655
Chord Roughness							-0.13	-0.17 – -0.10	< **.001**
Semitonal Voice Leading to V							0.12	0.08 – 0.15	< **.001**
Descending-Fifths Root Motion							0.26	0.18 – 0.35	< **.001**
Presence of $\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, and/or $\hat{6}$							0.07	0.04 – 0.10	< **.001**
Music Theory Training							0.06	-0.08 – 0.19	.397
Random Effects									
σ2	1.2			1.19			0.76		
τ00	$0.49_{\text{participant}}$			$0.49_{\text{participant}}$			$0.09_{\text{participant}}$		
τ11							$0.12_{\text{music theory training}}$		
ρ01							$-0.20_{\text{participant}}$		
ICC	0.29			0.29			0.22		
N	$59_{\text{participant}}$			$59_{\text{participant}}$			$59_{\text{participant}}$		
Observations	3658			3658			3658		
Marginal R^2	.031			.045			.047		
Conditional R^2	.310			.323			.253		

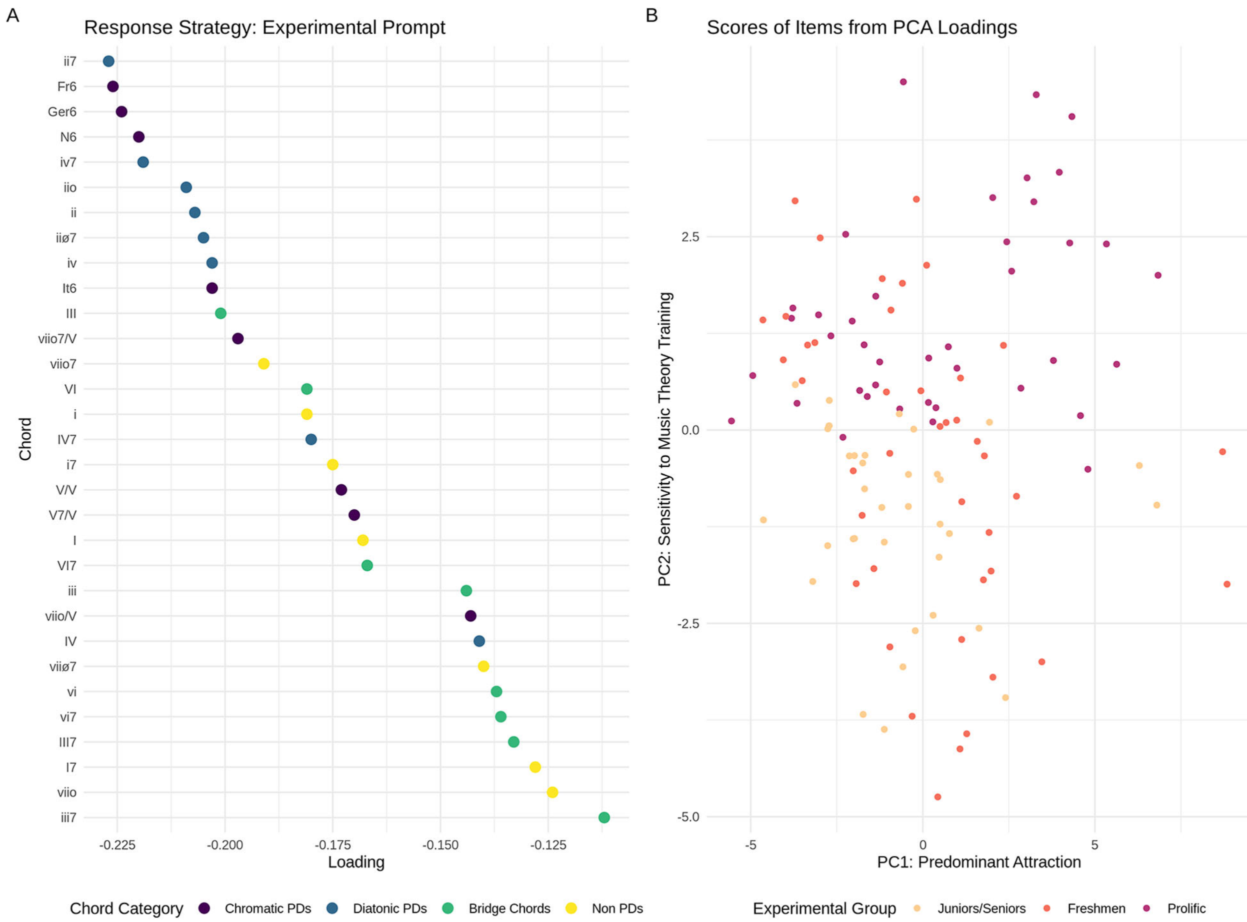

FIGURE 3. Principal component analyses.

across all ratings of participants ($N = 118$). We extracted 31 components, but only interpreted the first two components, which cumulatively explain 39% of the variance in our data. To facilitate explaining our interpretation of these components, results from the first two components are displayed in Figure 3. We labeled the first principal component "Pre-Dominant Attraction" because items that load highly on this component reflect the primary response strategy of rating how attracted the target chord was to the dominant chord. This consistency in response strategy is evident from the fact that all items on the first component load in the same direction; chromatic and diatonic pre-dominant chords load highly in Figure 3A whereas bridge chords and non-pre-dominant chords do not. This first factor reflected 27% of the variance. We labeled the second principal component "Sensitivity to Music Theory Training" because when the loadings were fed back through the individual response data, an individual's score on the second principal component visually separated the ratings from participants based on their music theory training, as evident from Figure 3B. This second factor reflected 12% of the variance.

Clustering Analysis. Second, we submitted the full set of computationally derived features described in Table 1 to a hierarchical agglomerative clustering algorithm. We did this to explore whether the five chord features used in our supervised analysis would provide new insight into how pre-dominant chords might be categorized. To do this, we first normalized all features, created a distance matrix using the R programming language, then ran the hclust() function over the distance matrix using complete linkage (James et al., 2013). The resulting dendrogram is visualized in Figure 4.

Discussion

This study aimed to determine the extent to which factors from the music theory and music cognition

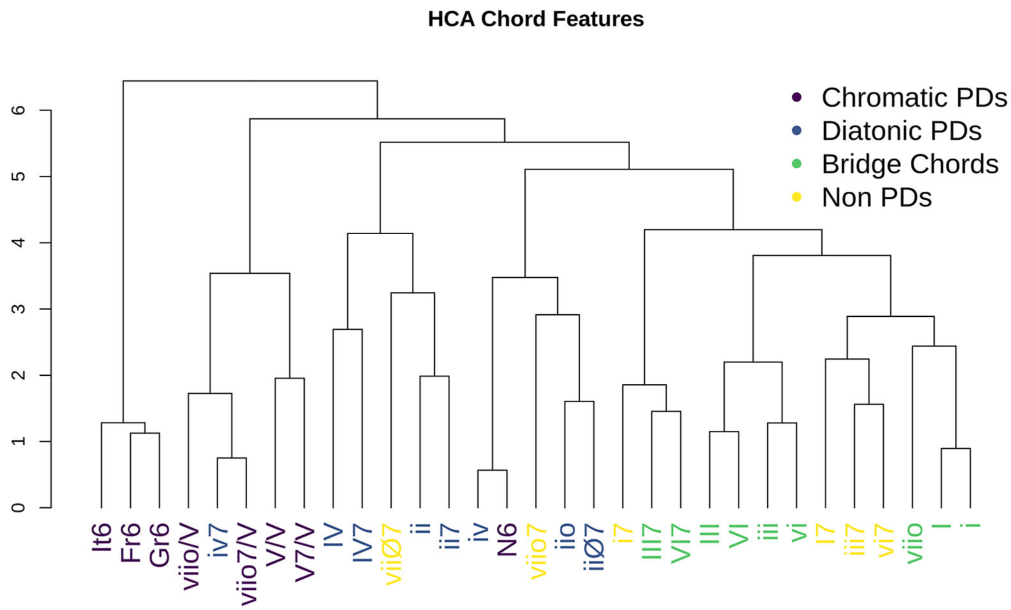

FIGURE 4. Clustering of chord features.

literature were predictive of ratings of attraction in an experimental, behavioral paradigm. To investigate this, we fit a series of regression models to assess the extent that each of our proposed factors were predictive of our attraction ratings. These included (1) a top-down model that categorized chords into four categories based on the music-theoretic literature, (2) the extent to which the music theory training an individual had received might moderate these ratings, and (3) a bottom-up model of musical features derived from calculations of each sonority. In addition to fitting several regression models to our data, we also conducted an analysis of our data using unsupervised methods. This choice in analysis was motivated by recent successes within both the music perception and computational musicology literature (Albrecht & Huron, 2014; Moss, 2019; White, 2014; White & Quinn, 2018) to better understand listener response strategies in the experimental paradigm. Below, we discuss the implications of each model in turn.

MODEL DISCUSSION

We predicted that categories of chords proposed by music theory textbooks would be predictive of ratings of attraction in our experimental paradigm. Using these top-down categories derived from reviewing the pedagogical literature on pre-dominant chords, we predicted that the chord categories with the highest ratings of attraction would be chromatic pre-dominants, followed by diatonic pre-dominants, bridge chords, and finally non-pre-dominants. As evident from the parameter estimations of the coefficients in the chord category model as seen in Table 2, this pattern generally held true with the exception of diatonic pre-dominants being descriptively estimated as the highest category rather than chromatic pre-dominants. When subjected to a statistical test, running a Tukey post hoc comparison of means revealed significant differences between all pairs of chord categories except comparing bridge chords with non-pre-dominants and also when comparing chromatic pre-dominants with diatonic pre-dominants. In other words, the two pre-dominant chord categories proposed by music theorists were rated significantly higher in terms of attraction from chords that would not be classified as pre-dominant but were not different from one another (Figure 2A).

While this was not an exact rank order reproduction of our predictions, the two pre-dominant chord groups being significantly different from the other chords used in the experiment is consistent with the assertion that a defining perceptual characteristic of attraction demarcates chords typically labeled as "pre-dominant" from other types of chords. As reported in Table 2, most of the variation in this model does not come from the fixed effects, with relatively small amounts of variance being explained by the fixed effects estimates as reflected by the model's marginal $R^2 = .03$. A much larger degree of variation was explained by the random effect of participant with the conditional $R^2 = .310$. Though we anticipated more variation being explained from the fixed effects, reflecting categories from the music theory literature, this finding motivated exploring other features such as an individual's music theory training, which is explored in the subsequent model.

In order to investigate the effect of music theory training as a potential moderator, for our second statistical model we fit another mixed effects model to our data with the music theory training variable interacting with the chord categories. This is motivated by literature suggesting that increased music training results in higher sensitivity to expert listening tasks (e.g., Arthurs et al., 2018; Bigand et al., 1996) and by the fact that the pre-dominant function is explicitly introduced gradually over several semesters in music theory curricula.

As evident from the model predictions displayed in Figure 2 and further detailed in the regression coefficient estimates in Table 2, individuals with higher music theory training rated pre-dominant chords as being more attracted to the dominant chord than those with less music theory training. Interpreting our model beginning with the interaction terms, music theory training significantly interacted with the main effects of chord category. Central to our hypotheses and most visibly evident from the significantly different positive slopes of the pre-dominant categories in Figure 2C, ratings of both diatonic and chromatic pre-dominant chords increased with music theory training.

Lastly, we were motivated to contrast our top-down model, which used prescribed categories from the music theory literature to categorize chords, with a bottom-up approach that formalized the assertion from our literature review that ratings of attraction could be determined by a chord's internal features (e.g., Shaffer et al., 2014). To do this, we fit a regression model predicting mean ratings of attraction using only features of the chords as discussed above. When simultaneously accounting for all our above features of interest, several of them contributed to the model significantly (Figure 2D): in order of increasing magnitude of the significantly contributing coefficients of the continuous variables were chords with scale degrees $\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, and $\hat{6}$, chords with more semitonal adjacency to V, chords that are less rough, and finally chords moving to V by descending fifth.

Finally, having modeled the data from our experiment using a series of regression models, we supplemented our analysis following recent uses of unsupervised statistical methods from the music cognition and computational musicology literature, noting the insights that unsupervised methods were able to afford in the recreation of presumed *a priori* musical concepts such as chord progressions (White & Quinn, 2018) and tonality (Albrecht & Huron, 2014; Moss, 2019). We carried out a principal component analysis to better understand response strategies of the listeners in our experiment. Using principal component analysis would also allow us to completely rely on participant ratings rather than presume that top-down or bottom-up features shape the response space.

Due to the single prompt used in the task, we expected that the first principal component would solely reflect a collective agreement regarding attraction among our listeners. For this reason we called it Pre-Dominant Attraction. As evident from Figure 3A, each item's loading on this component reflected the degree to which one of the target chords aligned with the experimental prompt. We have confidence in this interpretation due to the fact that all items loaded in the same direction and when ordered in terms of magnitude of loading on the component, the ordering of chords as shown on the y-axis of Figure 3A generally align with our first research question's predicted orderings as distinguished by the color mappings.

Following Nobile's (2016) assertion that the pre-dominant is syntactic, an empirical approach to understanding the function would be to consider PC1 as a way to compare the "pre-dominantness" of 31 harmonies and a new ranking of PD attraction. Indeed, Figure 3A illustrates the claims of pre-dominant successions found in music theory textbooks (discussed in our introduction) within this ranking: the Ger^6 is rated higher than iv, ii is ranked higher than IV, etc. While a similar listing could have been generated by averaging across all chord ratings then sorting participant response, using principal component analysis affords the ability to now explore subsequent components independent of the primary response strategy of responding to the prompt, as we interpret in the next principal component.

The vertical dimension of Figure 3B visualizes the values of each of the 118 chord ratings from our experiment when weighted with the loadings from the second principal component. Of particular interest is the almost perfect separation between the positively scored individuals who took the experiment on www.prolific.co (who generally have less music theory training) versus the music students who scored negatively on this dimension. Given that scores on the second principal component are able to demarcate individuals with and without music theory training, we labeled this component as "Sensitivity to Music Theory Training" and this component explained 12% of the variance of our data.

An individual's score on the second principal component provides a visually reliable classification of whether an individual had received musical theory training or not. Said another way, we could determine an individual's music theory training background based solely on their response in the experimental paradigm. Future research could consider the reproducibility of this finding, as it would provide a promising avenue to study the development of listener response strategies.

In our final analysis, we considered how chords might group together from their musical features alone. To investigate this, we ran a hierarchical clustering analysis with complete linkage on the computationally derived features shown in Figure 4. At lower levels of the clustering analysis, chords that share salient features tend to group together, as exemplified by the augmented sixth chords grouping together (left side of Figure 4) and non-pre-dominant chords group together (right side); but as we ascend the dendrogram, groupings might suggest new pre-dominant categories to consider.

Our goal in performing this analysis was to gain possible new insights into ways that the class of pre-dominant chords could be conceptualized, but upon deeper reflection of the output of this algorithm, the results heavily depend on the feature space submitted to the algorithm. For example, several of the features of interest in the matrix are devoted to describing voice-leading elements such as the inclusion of chromatic scale degrees, which might explain the clear separation of the augmented sixth chords. It follows that variables designed to capture certain features about a chord or type of chord will and should group together with agglomerative methods. While this is a feature of this type of clustering algorithm, this does highlight a serious circularity that both music psychologists and theorists need to consider in defining pre-dominant chords. Features that are ascribed as defining the pre-dominant category arise via inductive processes and the inductive features of interest then define the bounds and subsequent shape of the feature space. While we might be able to provide some new partitions of pre-dominant chords, any novel groups that we posit or would emerge from analyses such as these would need to be tested with perceptual data on sets of features of chords that extend far beyond those presented here in order to ensure robustness. This requires the work of both music theorists and music psychologists to help shape the features of interest.

LIMITATIONS

We note three additional limitations of our experiment. The first is related to the Prolific participants, who may have been unfamiliar with the notion of chordal attraction, and we cannot be sure if the Prolific participants were conceptualizing the experiment similar to music majors. Per the discussion of the second principal component, we have empirical evidence that they exhibited a different response pattern, but they may have been responding to different factors or were less sensitive to subtle pitch differences among chords. Prolific participants may have been responding to tonal "fit," as evidenced by the fact that with the exception of the V/V chord and the iv chord, Prolific participants rated all diatonic major/minor triads from the major mode (i.e., I, ii, iii, IV, vi) as having the highest attraction to V. This finding is consistent with Huron (2006), who notes that listeners assume a major mode before ever hearing a music stimulus, given the assertion that nearly three-quarters of Western music is major. Unlike Peabody music majors, Prolific participants were unmonitored, and we were concerned that they may not have been fully attentive to the task or completed the experiment in a noisy environment; there were no "catch trials" used. However, the fact that they rated all diatonic major and minor triads from the major mode highest suggests that they were listening closely and responding to the C tonality of the trials.

A second possible confound pertains to the construction of stimuli. While we used Shepard tones to attempt to control for possible effects of register, contour, and chordal inversion (e.g., Lahdelma & Eerola, 2016a, 2016b; Roberts & Shaw, 1984), Shepard tones might have been a timbre alien to all participants, possibly deterring them from making judgments based on their past musical experiences. Further, the use of block chords may have evoked a texture similar to Bach chorales, particularly for musicians, and they may have responded with this specific style in mind (conversely, this might have been a less-familiar style to Prolific participants). This limitation also provides an avenue for future research, as the role of voice leading (especially bass motion) in pre-dominant attraction could be explored. The current experiment could be replicated with complex tones, and Lerdahl's (2001) melodic attraction values could then be used as a basis for hypotheses. Stimuli could include trials in different inversions to test the possibility that inverted triads have more attraction in a pre-dominant context.

Finally, we also highlight the perennial problem when modeling musical features, in that they will always share both theoretical and empirical overlap. For example, we incorporated Lerdahl's Chord Distance metric, which bears overlap with measures of the Descending-Fifths Root Motion feature. Lerdahl's metric involves a measure of overall key relationship and is a monument in this empirical domain, and the descending-fifths relationship is likewise a methodological mainstay for chord syntax in theory textbooks. Statistical techniques such as multiple regression are not able to disentangle these nuanced relationships and further highlights the need for more empirical work with designs that consider these dependencies and the addition of other features of interest such as a chord's mode, quality, presence of a chordal seventh, all of which will covary with features such as scale degree and roughness.

IMPLICATIONS AND FUTURE DIRECTIONS

Results from this analysis might guide theory pedagogy. Participants rated chords from the two pre-dominant categories as distinctly higher than their non-pre-dominant counterparts using only the mental schema of attraction. We found a pattern of responses that is consistent across music theory training, one that is not driven by outlier effects of a subset of listeners that reliably employ this response strategy. This suggests that music theory teachers might further utilize this metaphor to facilitate explaining aural identification of pre-dominant chords. Moreover, instructors of aural skills may find success in directing student attention toward features that better capture a chord's attraction and thus their pre-dominant status. Asking students to explicitly attend to chords whose roots move down by fifth, to chords with less roughness, to chords that have more semitonal adjacency to V, and to chords containing scale degrees $\hat{4}$, $\sharp\hat{4}$, $\flat\hat{6}$, and $\hat{6}$, might be effective listening strategies for hearing the pre-dominant function. Still, considering the modeling of our collapsed feature-based dataset, we caution the over interpretation of the features we report here, highlighting that our summary features do not take into account chord voicings. Future work that looks to use internal characteristics of a chord to predict ratings of attraction should consider the perceptually salient feature of chord voicing and might constrain the almost limitless ways to consider voicing chords using recently proposed taxonomies on consonance and dissonance (Harrison, 2020).

Investigation into how participants develop the kind of fine-tuned listening sensitivity suggested here highlights another issue worth addressing. In this experiment we wanted to measure our music training variable as validly and reliably as possible. Specifically, we tacitly assumed a latent causal mechanism between music theory training and listening sensitivity. In order to best capture this relationship, we sought to measure music training as a continuous variable in order to avoid dichotomizing since we intentionally recruited from three different populations of listeners in order to ensure we could model a representative sample. Since we were specifically interested in music theory training, we used a single, Likert-scale item from the Gold-MSI (Müllensiefen et al., 2014) rather than using one of the composite factors (Baker, Ventura, Calamia, Shanahan, & Elliott, 2018). Additionally, we ran this analysis with the music training subscore and found a similar pattern of results, presumably due to the collinearity between the items; we chose to use music theory training because it is more interpretable in the context of regression and better aligns with our theorized causal mechanism.

Psychometric tools like the Gold-MSI were developed for broad questions of assessing musical sophistication in the general population, but in our case provide only a coarse measurement for the level of listening sensitivity we hoped to measure. This highlights the need for either psychometric tools designed for expert listening or clearer links between our theoretical frameworks and theories and prediction we make about our data (Guest & Martin, 2021). A more robust method of surveying music theory training would be welcome to these authors and could have important implications for future research of this type. An improved method of assessing music theory training would then help address a larger question about these data. Indeed, we cannot be sure whether these findings are due to passive exposure to (Western Classical) music or explicit training in music theory classes.

Similarly, while we chose to model music theory training as a constant, linear function in Figure 2C, future lines of research might consider investigating the nature of this listening sensitivity. It may be that listeners do indeed linearly accumulate sensitivity to pre-dominant chords over the years of their music theory training, but the true nature of this learning function might more accurately be modeled using a function that allows for faster growth upon exposure to a new listening technique. Understanding how these expert listening skills are acquired would be helpful to informing best practices for teaching harmonic listening skills. Indeed, the factors involved in harmonic dictation are under-explored in the literature (Chenette, Phillips, & Wood, 2019). Following Karpinski (2000) and others, this research is another attempt to bridge the gap between cognitive research and aural skills pedagogy, this time with a focus on understanding the perception of the pre-dominant, an underexplored and under-theorized harmonic function.

Participant listening habits may play a role in the perception of pre-dominant attraction, as particular genres treat the pre-dominant function differently and harmonic frequencies within these corpora may affect attraction ratings. Indeed, Vuvan and Hughes (2019) have suggested that harmonic expectancies change based upon the musical style participants hear. A next step could be to directly test the relationship between listening habits and pre-dominant attraction, as we have already observed that respondents from the general population (Prolific participants) did not exhibit the same pattern of response as our musically trained sample, possibly because they are likely exposed to more popular music than Western Classical art music.

In tandem with behavioral research, investigations of the pre-dominant function in different music datasets could also be conducted to see whether attraction is related to chord frequencies and distributions. Further, a chord's contextual placement may also affect the perception of pre-dominant attraction. For example, chords preceding V may differ in attraction depending on whether the V is at a cadence; theorists have argued (Caplin, 1998, p. 27) and tested (Sears, Caplin, & McAdams, 2014) that a pre-dominant is required for tonal closure. Indeed, the augmented sixth chord is scant even within Western tonal musical repertoires but appears most often at form-defining cadences: perhaps the relative attraction of any pre-dominant chord is influenced by its normative context, such that the augmented sixth chord, for instance, is marked for consciousness—memorable only to those with specialized training and magnified further for those familiar with the repertoire (Tan, Brown, & Lin, 2021).

Finally, these findings may be used as a starting point to investigate a larger theory of the "pre-dominant complex": two or more chords functioning as pre-dominants before V. A theory of chord "ordering" within the pre-dominant function is underexplored. For example, while participants heard the ii chord rather than IV as having a higher attraction to the dominant, we did not directly test the perception of IV–ii–V versus ii–IV–V. In a future study, participants could rate attraction on a slider when hearing progressions of more than four chords, which would include a pre-dominant complex: tonic, multiple pre-dominant chords, dominant, tonic. Findings may be used to construct a perceptual schematic akin to the familiar diagram of chord successions provided by Kostka and Payne (2009; Figure 1); an initial step would be to include chromatic pre-dominants in such a schematic, which are hypothesized to occur between the diatonic pre-dominants and the dominant. A broader investigation, still, would consider the impact of chordal metric placement on perceived attraction (White, 2020b). These future explorations would offer teachers and analysts further insights into the experience of chord-to-chord successions in tonal contexts.

Conclusions

Observations from the music theory literature allow us to take a nuanced, historically informed appraisal of established chord categories in relation to the under-researched pre-dominant function. The tools from music psychology allow us to operationalize and quantify these assumptions so they can be investigated systematically. In this paper, we presented evidence that the groups of chords regarded as pre-dominant are rated by listeners as categorically different on the dimension of attraction, one of the proposed perceptually salient features of the pre-dominant function. Further, these ratings of attraction are moderated by measures of music theory training, suggesting that exposure to this pedagogy encourages listeners to become more sensitive to the schema of attraction. In line with pedagogical assertions, we also presented evidence to suggest that a chord's internal characteristics aid in predicting the degree of attraction rated by listeners. Based on this experimental evidence, we have proposed several lines of future work, including investigating the developmental trajectory of how these expert skills are acquired and further ways to explore the pre-dominant function.

Author Note

We are grateful to those who provided assistance on this study. Cory Bonn designed the experimental interface in Qualtrics. Sebastian Bisciglia created a program that calculates the roughness value of a chord using Parncutt's algorithm. Kristen Antunes made each of the Shepard tone trials, and Vicky Gange used the GUI that Dr. Bisciglia made to determine roughness values for each trial. We would like to thank Peter Miksza for suggestions at an early stage of this research, and we also wish to express our appreciation to the editors and reviewers of this article.

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article. A Faculty Development Grant awarded by the Dean at the Peabody Conservatory supported some of this work.

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