

Incidentally acquiring pitch-label associations with a musical contingency learning task

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Abstract

1
2 Incidental learning occurs rather rapidly and effortlessly in a range of different domains, such
3 as early language acquisition, motor learning, and a wide range of more arbitrary laboratory
4 tasks. The present report explores the efficacy of an incidental learning task in the acquisition
5 of pitch-label associations, that is, the ability to identify and name musical notes by ear. In
6 experiment 1, 2 and 3 participants were asked to respond to the target (a note name) while
7 ignoring the cues (either a tone or, in one experiment, a tone with a note position). In a pretest
8 and posttest, we further analyzed their ability to guess the name of the tone in a tone naming
9 task. We also explored the role of intentionality in acquiring and remembering pitch-label
10 associations, but there were only small suggestive trends for slightly better performance for a
11 group instructed to try to learn the contingencies compared to a purely incidental learning group
12 (i.e., with no instructions about the contingencies), suggesting that learning is at least primarily
13 incidental. Our research opens up new venues for the investigations of incidental learning
14 related to the acquisition of musical features useful to performance (how to play).

15
16 **Keywords:** pitch identification, contingency learning, music learning, instruction, pitch

1 to trials coherent with the regularity, termed *high contingency* (e.g., “move” in blue), than to
2 trials incoherent with the regularity (e.g., “move” in red), termed *low contingency*.

3 In similar tasks, many different stimulus dimensions have been used for both the task-
4 irrelevant cue (e.g., shapes, words, nonwords, colors) and task-relevant target (e.g., colors, color
5 words, neutral words, positive/negatively-valenced words; Forrin & MacLeod, 2017; Levin &
6 Tzelgov, 2016; Schmidt & De Houwer, 2012a, 2012b, 2012c). Learning is always very rapid
7 and the pattern of results is always the same, that is, faster and more accurate responding to
8 high relative to low contingency trials. Similarly fast learning is observed in other incidental
9 learning procedures such as sequence learning (Bianco et al., 2020; Nissen & Bullemer, 1987;
10 Turk-Browne et al., 2005; Woods & McDermott, 2018), artificial-grammar learning (Reber,
11 1967; for a review, see Pothos, 2007), the Hebb digits task (McKelvie, 1987; Oberauer et al.,
12 2015; Vachon et al., 2018), and hidden covariation detection (Lewicki, 1985, 1986; Lewicki et
13 al., 1992).

14 The present report explores the efficacy of an incidental learning task in the acquisition
15 of pitch-label associations, that is, the ability to identify and name musical notes by ear.
16 Although incidental learning has been robustly observed with a wide range of different stimulus
17 materials, learning to name musical pitches by ear is a particularly interesting case. As discussed
18 below, in the music cognition and musicology literatures this particular skill is considered to be
19 especially difficult to master, perhaps even impossible for most adults. This might suggest a
20 particular (and surprising) boundary condition on incidental learning. On the other hand, if
21 learning to identify pitches by ear is learnable incidentally, the present work might suggest
22 future avenues for aiding novice musicians in acquiring this skill.

23

1 **Incidental Learning in Music**

2 Formal instruction and deliberate learning obviously are fundamental for understanding
3 musical theory and becoming an expert musician. However, most people, even nonmusicians,
4 possess some music competences that they gained from mere exposure (Bigand & Poulin-
5 Charronnat, 2006; Rohrmeier & Rebuschat, 2012). For instance, we can all easily recognize
6 and correctly reproduce (e.g., by humming) a familiar melody without having explicit
7 knowledge of the music grammar. The incidental (and implicit) learning of musical material
8 has been already investigated in prior work, such as the acquisition of sequence information
9 linked to melody (Saffran et al., 1999, 2000; Tillmann & Poulin-Charronnat, 2010), timbre
10 (Bigand et al., 1998), harmony (Bly et al., 2009; Loui et al., 2009; Rohrmeier & Cross, 2009),
11 and rhythm (Brandon et al., 2012; Salidis, 2001; Schultz et al., 2013; Tillmann et al., 2011).
12 Much as with more arbitrary materials, such as in colour-word contingency learning, artificial
13 grammar learning, sequence learning, or hidden covariation detection tasks, regularities in
14 musical materials are also learned rapidly and robustly.

15 Recently, in a series of studies (Iorio et al., 2023; Schmidt et al., 2023), we applied a
16 similar logic to the more ecological case of acquiring sight-reading skills. Using a musical
17 contingency learning procedure, participants were asked to identify note names (the relevant
18 stimulus or target) while ignoring note positions (the irrelevant stimulus or cue). Critically, each
19 note position was presented much more frequently with the congruent note name (e.g., “do”
20 was written inside of the note position for “do” much more often than incongruent note names).
21 Although the participants were not informed about or instructed to pay attention to these
22 contingencies, nonmusicians learned note name/note position associations and they were able
23 to correctly use their knowledge in a note naming test. Again, learning was very fast. The entire
24 experiment lasted about 20 minutes and robust learning was already observed within this period.

1 One of the reasons why incidental learning appears so quickly is the large numbers of
2 trials that participants experience in a very short time. That is, participants gain substantial
3 practice with novel stimuli rapidly. For instance, in some of our music learning studies
4 mentioned above, participants saw 336 trials in roughly 15 minutes. As such, this type of
5 learning procedure allows for rapid automatization. We also saw this in our performance
6 measures. For example, nonmusicians participants responded robustly faster to congruent than
7 to incongruent trials during the learning phase. This suggests that participants have not only
8 learned the meanings of the note positions, but that seeing a note position provokes a very rapid
9 retrieval of the corresponding note name.

10

11 **Pitch Identification: A Special Case?**

12 Surprisingly, the same types of incidental learning tasks have not been used to explore
13 whether participants are able to learn to identify pitches by ear and to internalize their pitch
14 identities. This is a particularly interesting question, both theoretically and practically, because
15 the ability to identify and name pitches by ear is considered to be so difficult that it may be
16 unlearnable by most. In particular, *absolute pitch (AP)* is the ability to name a pitch by ear (for
17 reviews, see Deutsch, 2013; Levitin, 2007). For instance, an AP possessor can hear a random
18 note played on an instrument without any initial context (e.g., hearing an initial note of known
19 pitch) and the AP possessor would be able to correctly name the note (e.g., “mi”), usually very
20 rapidly and with little effort.

21 In the current report, we do not study AP possessors or the ability to acquire true AP.
22 However, the difficulty of acquiring AP suggests that there might be something fundamentally
23 difficult about learning pitch-label associations. Although the criteria for determining what
24 “counts” as AP varies rather unsystematically in the literature, AP possessors identify pitches
25 quite accurately (Levitin & Rogers, 2005; Miyazaki, 1988). Their pitch identification is not

1 always perfect, but their errors tend to be very close to the correct response (e.g., ± 1 semitone).
2 Further, their identification of pitches by ear is very automatic, with response times generally
3 between 1.5 and 3 seconds according to some reports (Bermudez & Zatorre, 2009; Miyazaki,
4 1990; Takeuchi & Hulse, 1993; Van Hedger et al., 2019; Wong, Lui, et al., 2020), or even as
5 rapid as 600 ms according to others (Refaat, 2014).

6 AP ability is rare, only present in a small percentage of the population (Miyazaki et al.,
7 2012; Takeuchi & Hulse, 1993; Ward, 1999), even among skilled musicians. Some authors
8 propose that there is a strong genetic component (Athos et al., 2007), supported by twin studies
9 (Theusch & Gitschier, 2011), early acquisition (Deutsch, 2013), and unique structured brain
10 circuitry (Bermudez & Zatorre, 2009; Loui et al., 2009; Schulze et al., 2009). Others have
11 suggested that there is a critical period, with AP rarely observed for those starting music training
12 after 4 or 5 years old (Crozier, 1997; Deutsch, 2013; Deutsch et al., 2006; Miyazaki & Ogawa,
13 2006), similar to the way that the ability to make phonemic distinctions that do not exist in the
14 native language rapidly reduces after a critical period in early language learning (e.g., Werker
15 & Tees, 1984).

16 The above-mentioned research on AP suggests an interesting question: Are the
17 associations between auditory pitches and their corresponding pitch names fundamentally
18 impossible (or very difficult) to learn (e.g., for adult AP non-possessors)? For instance, is there
19 something “special” about musical notes that makes it almost impossible to learn how to
20 associate a note name with them? If the response to this type of question is affirmative, then
21 this would seem rather surprising from the lens of research on incidental learning. As long as
22 the regularity to learn is relatively simple (e.g., as is the case when learning simple pairings
23 between auditory pitches and note names), learning tends to be rather rapid and robust and does
24 not seem to have a strong modality sensitivity. Whether we are asking participants to learn an
25 artificial grammar from an auditory artificial speech stream, to learn pairings between words

1 and colours, between nonwords and emotional stimuli, or a wide range of other types of
2 stimulus pairings, participants generally have no difficulty learning such regularities. Why
3 would note pitches (or the relationships between note pitches and their corresponding names)
4 be any different? To explore this question in the present work we developed an incidental
5 learning task that is structurally similar to other types of incidental learning tasks with
6 nonmusical (or other types of musical) materials. We then ask whether the same type of rapid
7 and effortless learning is observed in a pitch-label learning task or whether there is evidence for
8 a fundamental difficulty in learning this specific type of stimulus pairing.

9

10 **Pitch Identification: Not So Special?**

11 Some research does suggest that the ability to name pitches by ear is easier than typically
12 assumed, at least at a more implicit level. To better appreciate what has been observed in
13 research on “implicit AP” (Deutsch, 2013; Levitin, 2007; Schellenberg & Trehub, 2003), it is
14 first relevant to make a distinction between absolute and relative pitch. *Relative pitch (RP)* is
15 the ability to identify and name pitches after receiving an external reference. Concretely, if we
16 play a context note and inform the RP possessor of its identity (e.g., “fa”) and then play a
17 different note (e.g., the pitch for “la”), then the RP possessor should be able to identify the
18 second note. RP possessors achieve this with a comparison-based strategy (Levitin, 1994;
19 Levitin & Rogers, 2005; Takeuchi & Hulse, 1993). They have therefore not learned the name
20 of each auditory pitch but can rather “calculate” the correct pitch name for a note via a
21 comparison with the context note of known pitch. Because of this, pitch naming is much less
22 automatic and rapid in RP possessors.

23 Work on what has sometimes been termed *implicit AP* indicates that most people, even
24 though categorized as “AP non-possessors”, are able to succeed at tasks that should be
25 impossible without AP. As an illustration, AP non-possessors are able to judge whether a

1 familiar piece of music is played in the correct key (Miyazaki & Rakowski, 2002), which should
2 not be possible with RP alone. That is, if a piece of music is simply transposed, for instance,
3 from C Major to B Major, all the intervals between notes remain identical. As such, detecting
4 that one version is correct (e.g., C Major) and that the other is incorrect (B Major) necessarily
5 requires detecting pitches absolutely. Similarly, AP non-possessors can correctly reproduce
6 familiar melodies (e.g., by humming) with a reasonable degree of accuracy (Levitin, 1994).
7 Again, this should only be possible with AP. RP would be insufficient to produce the pitches
8 absolutely, and many of the participants studied in this type of research possessed neither (i.e.,
9 non-musicians without AP or RP). These results might be taken to suggest that there is
10 something fundamentally wrong with the idea that pitch-label associations are nearly
11 impossible to learn. Alternatively, it might be proposed that pitch-label associations are
12 learnable implicitly but not explicitly.

13 However, some other recent studies (Van Hedger et al., 2019; Wong, Lui, et al., 2020;
14 Wong, Ngan, et al., 2020) have hinted that some adults might be able learn AP, even at an
15 explicit level. They demonstrated that after explicit, extended, and effortful training, adults
16 (musicians and non-musicians) were able to improve their speed and accuracy in pitch
17 identification tasks. Some showed performance at posttest similar to true AP possessors. This
18 work is not without its critics, however. For instance, participants with accurate posttest scores
19 often had pretest scores that were already reasonably good, thus demonstrating only moderate
20 improvements. It is not necessarily controversial to suggest that pitch identification can be
21 improved, but the general consensus seems to be that such improvements are likely to be
22 minimal and that it is implausible to think that someone without any pitch identification abilities
23 at all could learn to easily and rapidly identify pitches beyond some of the stricter criteria.

24 In any case, our goals are notably different than the pre-existing research discussed
25 above. Past work has used extended and explicit training to determine whether some

1 participants are able to achieve AP-level performance after training and how much of an
2 improvement is possible. The current work does not aim to address such questions. Rather, our
3 goal is to determine whether rapid and robust acquisition and improvement of pitch-label
4 associations is possible at all in an incidental learning task. In particular, much of the research
5 discussed above would suggest that pitch identification is uniquely difficult. As such, the
6 procedures that work quite rapidly for learning other types of associations (i.e., incidental
7 learning procedures) may not be nearly as effective when trying to acquire pitch-label
8 associations. Our basic postulate, however, is that this notion is likely false, and that rapid
9 learning and improvement of pitch-label associations should be possible. We also note in
10 advance that the learning we observe may or may not be comparable to true AP perception, a
11 point to which we will return in the General Discussion.

12

13 **Current Work: The Music Contingency Learning Procedure**

14 The goal of the present work is to explore the learnability of pitch-label associations in
15 an incidental learning task. We note in advance that we take a simplified approach to studying
16 early learning. For instance, artificial grammar learning studies do not have participants learn
17 the entire grammar of an entire language, but rather researchers create a limited set of grammar
18 rules with a small number of letters to assess the degree to which grammar rules are learnable
19 incidentally (for instance, see Saffran et al., 1999). Similarly, in the present work, we do not
20 train participants with all the semitones from multiple octaves and timbres (i.e., instruments)
21 and test them with strict tests of AP (e.g., Van Hedger et al., 2019; Wong, Lui, et al., 2020;
22 Wong, Ngan, et al., 2020). Instead, we train participants with a smaller number of stimuli in a
23 task highly similar to other incidental learning tasks (e.g., Iorio et al., 2023; Schmidt et al.,
24 2007) to see whether pitch-name associations pose a particular difficulty for participants and to
25 what degree participants can automatize pitch-label associations.

1 Auditory musical Stroop procedures are one way to easily assess the automaticity of
2 pitch processing (Akiva-Kabiri & Henik, 2012; Hamers & Lambert, 1972; Leboe & Mondor,
3 2007). Generally, in these procedures participants are asked to respond to a relevant stimulus
4 while ignoring an irrelevant stimulus that is either congruent (e.g., the word “high” presented
5 in a high-pitched voice) or incongruent (e.g., the word “high” presented in a low-pitched voice),
6 analogous to colour-word Stroop tasks (see MacLeod, 1991, for a review) or sight-reading
7 music Stroop tasks (see Grégoire et al., 2013). Faster RTs for congruent trials compared to
8 incongruent trials indicates that pitch processing is automatic. That is, although participants are
9 asked to respond to the words, they cannot avoid processing the pitch, resulting in slower RTs
10 when the association between the stimuli is incongruent. In one experiment, Akiva-Kabiri &
11 Henik (2012) compared performance in a tone naming task and note naming task between AP
12 possessors and non-possessors. In the tone naming task, participants were asked to respond to
13 the tone while ignoring the note name. In the note naming task, participants were asked to do
14 the reverse (i.e., to respond to the note name while ignoring the tone). They found a congruency
15 effect for AP possessors only in the note naming task and a congruency effect in the tone naming
16 task for non-AP possessors, suggesting that only AP possessors are automatically biased by
17 pitches when identifying note names.

18 Of course, this work compared those with pre-existing pitch identification skills (i.e.,
19 AP possessors) with those that do not already possess such skills (i.e., AP non-possessors). Our
20 goal, in contrast, is to study learning of pitch detection abilities. It was our hypothesis that
21 participants can not only be trained to improve accuracy in pitch identification but will also
22 show evidence of automaticity in performance measures. In the following studies we use an
23 auditory adaptation of the above-mentioned musical contingency learning task (Iorio et al.,
24 2023) to measure the automaticity of pitch processing in nonmusicians and musicians.
25 Analogous to the manipulation we used in the sight-reading learning procedure, participants

1 heard a tone (cue) and then they were asked to respond to the note name (target) that appeared
 2 in the center of the screen. The note name was presented much more often with its congruent
 3 tone (e.g., the name “do” with the tone “do”) than with any other of the incongruent tones (e.g.,
 4 the name “mi” with the tone “do”), as illustrated in Table 1.

5 **Table 1**

6 *Contingency manipulation*

7

Note Name	Tone						
	fa	sol	la	si	do	ré	mi
fa	18	1	1	1	1	1	1
sol	1	18	1	1	1	1	1
la	1	1	18	1	1	1	1
si	1	1	1	18	1	1	1
do	1	1	1	1	18	1	1
ré	1	1	1	1	1	18	1
mi	1	1	1	1	1	1	18

8 *Note.* In the table is represented the contingency proportion between high contingency trials
 9 (presented 80% or 18 times) and low contingency trials (presented 20% or 1 time each). For
 10 instance, the tone “fa” is presented much more often with the note name “fa” (high
 11 contingency trials) than with the other note names (low contingency trials).

12 Our key hypothesis is that participants will be able to learn (or improve) their pitch
 13 identification abilities. This should be reflected both in an increase in explicit identification of
 14 note pitches after training, and more automatic effects on performance (i.e., faster responses to
 15 high-contingency congruent trials relative to low-contingency incongruent trials).

16

17

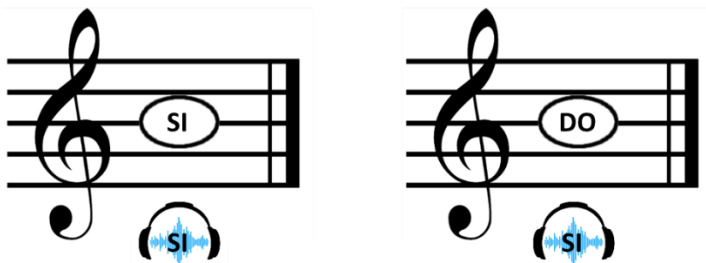
Experiment 1

18 In Experiment 1, we wanted to investigate whether nonmusicians were able to
 19 incidentally learn pitch-label associations. Nonmusicians are an interesting group to study,
 20 because normally they will have little or no practice with pitch identification. They are thus a
 21 naïve control group, and similar also to beginner musicians. For this purpose, we used a
 22 modified version of the musical contingency learning procedure from our previous studies

1 (Iorio et al., 2023; Schmidt et al., 2023), as discussed in the Introduction. Because previous
2 research suggested that a combined presentation of both note positions and tones can benefit
3 the acquisition of musical skills such as sight-reading (Mishra, 2014), one might posit that
4 learning to identify pitches by ear would also be improved by presenting musical notation as a
5 supplementary visual cue. We therefore compared two groups that were exposed to different
6 cue-target associations. In the tone-cue group, only tones were used as cues (i.e., the only visual
7 stimulus was the target note name). In the multiple-cues group, however, both note positions
8 and tones were used as cues. Specifically, participants were presented with a musical staff. A
9 note was presented in one of the positions of the music staff at the same time as the tone. The
10 note position and tone always matched. As in the tone-cue group, the tone (and note position)
11 was predictive of the target note name, the latter of which was presented inside of the note
12 position.

13 **Figure 1**

14 *Example of high and low trials*



15
16 *Note.* An example of high/congruent trial on the left in which the tone, the note position and
17 the note name matched. On the right there is an example of low/incongruent trial where the
18 tone and the note position matched between themselves, but not with the note name.

19 Our primary hypothesis is that both groups of nonmusicians will incidentally learn the
20 pitch-label associations. We hypothesize that participants will learn the associations quickly,
21 showing both improved accuracy in explicit pitch identification during the test phase and
22 automatic effects on performance during the learning phase. In particular, we anticipate faster
23 responses to congruent (high-contingency) trials than to incongruent (low-contingency) trials

1 (see Figure 1 for an example of high- and low- contingency trials). Concerning the group factor,
2 we considered two contrasting hypotheses. First, we might expect larger learning effects in the
3 multiple-cues group compared to the tone-cue group. The combination of the note positions
4 along with the tones might reinforce learning of the tone-label associations. On the other hand,
5 another possibility is that adding in a second cue actually impairs learning about the tone-label
6 associations. This might result if there is overshadowing (I. P. Pavlov, 1927). *Overshadowing*
7 is the observation that the learning of one regularity is impaired by the simultaneous learning
8 of another regularity. Specifically, the presence of associations between note positions and note
9 names might impair the learning of associations between tones and note names, and this because
10 participants learn the regularities between the note positions and note names *instead of* the
11 associations between pitches and note names (for more discussion of theories of
12 overshadowing, see the General Discussion). This group factor was largely exploratory, as we
13 did not have strong a priori prediction for either of the two contrasting hypotheses mentioned
14 above.

15

16 **Method**

17 *Participants*

18 119 participants, recruited online on Prolific.co, were randomly assigned to one of the
19 two experimental conditions described below (59 participants in the multiple-cues group and
20 60 in the tone-cue group) and received monetary compensation (3.80 £) for their participation.
21 Our inclusion criteria, mentioned in the recruitment advertisement, were being able to
22 understand French, being between 18-30 years old, not being a musician, and not being able to
23 read musical notation. 16 participants reported having absolute pitch. Precisely, 15,25%
24 participants (9 of 59) in the multiple-cues group and 11,66% participants (7 of 60) in the tone-
25 cue group answered yes to the subjective awareness question regarding absolute pitch. Overall,

1 their performance on the pretest (in which they were asked to guess the name of the tones) were
2 not significantly higher than the performance of the remaining 103 participants that did not
3 claim to have perfect pitch: $t(117) = .044$, $p = .946$, $d = .012$, $BF_{10} = .271$, $M_{\text{absolute pitch participants}}$
4 $= 16.7\%$, $SD = 9.52$, highest score = 33.33%; $M_{\text{remaining participants}} = 16.8\%$, $SD = 14.0$ highest
5 score = 85.71%. Therefore, we did not exclude these participants from the analysis. However,
6 although three participants in the tone-cue group declared that they did not have absolute pitch,
7 their performance in the pretest were between 60% and 100%, similar to AP possessors'
8 performance reported in the literature (Levitin & Rogers, 2005; Miyazaki, 1988). For this
9 reason, these participants were excluded from the following analysis.

10 Ethical review and approval were not required for the study on human participants in
11 accordance with the local legislation and institutional requirements. All participants accepted a
12 written consent before beginning the study. All the procedures were conducted in accordance
13 with the Declaration of Helsinki. Participants' anonymization was guaranteed.

14 *Apparatus, Design, and Procedure*

15 The experiment was programmed and run with Psytoolkit, a web-based software that
16 allows reliable RTs as shown from previous research (Stoet, 2010, 2016), also with musical
17 stimuli (Armitage & Eerola, 2020). The auditory stimuli were pure sinewaves that were created
18 using Audacity software with the lowest pitch being the “fa” (or “F”) note at the frequency of
19 349.228 Hz and the highest pitch being the “mi” (or “E”) note at the frequency of 659.255 Hz.
20 The “la” (or “A”) pitch was thus tuned to the standard tuning at the frequency of 440 Hz. To
21 ensure that headphones or speakers were correctly working during the task, participants
22 completed a sound check before starting the experiment.

23 During the main parts of the experiment, participants responded with the Z-I keys on a
24 standard AZERTY keyboard. However, because the experiment was online and it involved
25 participants from different countries (though AZERTY is standard in French-speaking

1 countries), an instruction referring to the type of keyboard needed in the study was added in the
2 recruitment advertisement. The keys Z, E, R, T, Y, U, and I were labelled according to the
3 sequence of the musical scale from the lower to upper position (i.e., fa, sol, la, si, do, ré, and
4 mi, respectively, referring to the French note names). The “O” and “N” keys were additionally
5 used to answer “Oui” (Yes) or “Non” (No) to the subjective awareness question, and the
6 spacebar was used to begin each phase from the instruction screens.

7 Before starting the experiment, we collected a subjective measure for AP in which
8 participants were asked whether they were able to name a tone without previously listening to
9 a reference note, translated from French:

10 *“Do you have perfect pitch, which means that you can name one or more tones when*
11 *listening without first having to hear an identified note serving as a reference?”*

12 This question was primarily used for screening purposes, along with the pretest scores, as
13 described above in the Participants section.

14 The experiment started with two practice phases, in which participants practiced and
15 automatized the note name-to-key assignments. During these phases participants were
16 presented only with the note names. The trial started with a fixation cross (“+”) in the center of
17 the screen for 500 ms, followed by a blank screen for 250 ms. A French note name (*fa, sol, la,*
18 *si, do, ré, or mi*) was then presented in the center of the screen until response (no time limit).
19 An on-screen key reminder (Z, E, R, T, Y, U, I) was added throughout the first practice phase
20 to help participants to learn the note name-to-key assignments. Following correct responses, the
21 next trial began immediately. Following incorrect responses, the note name changed color to
22 red and stayed on the screen until the participant pressed the correct key. The second practice
23 phase was identical in all respects, except that the on-screen key reminder was removed and
24 participants were encouraged to try to respond from memory. There were 70 trials in each
25 practice phase (140 trials in total).

1 **Figure 2**2 *Schematic description of the pre/posttest phases*

3

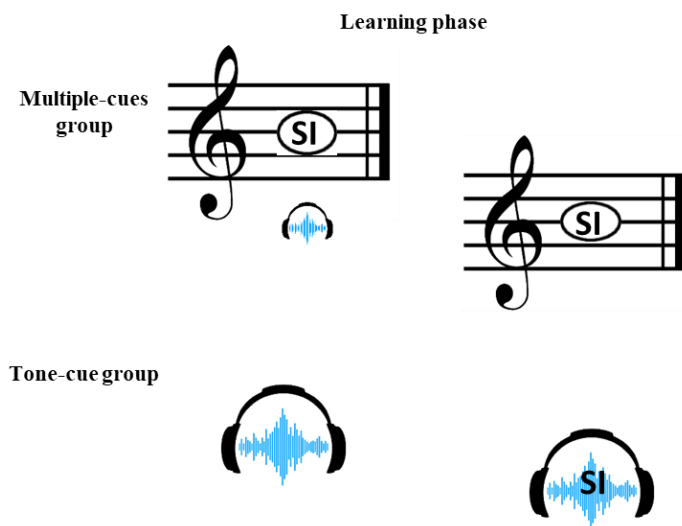
4 *Note.* Both groups were presented with the tone naming task, in which they had to guess the
5 name of the tone. The note-position naming task was presented only in the multiple-cues
6 group.

7 Before beginning a test phase, participants were randomly assigned to one of the two
8 groups (multiple-cues and tone-cue groups). While in the multiple-cues group the target was
9 preceded by both a note position and a tone (predictive cues), in the tone-cue group the note
10 name was only preceded by a tone. The procedure was otherwise identical for the two groups,
11 with exceptions noted below. A pretest phase, which measures the ability of the participant to
12 discriminate (e.g., better-than-chance guessing) between experienced and unexperienced events
13 (Cheesman & Merikle, 1984), followed the practice phases. The pretest (42 trials in total)
14 allowed us to assess the ability of participants to identify tones (and note-positions in the
15 multiple-cues group) prior to learning. Specifically, we were interested in knowing whether our
16 participants were able to recognize and name the tones (and note-positions) used as our
17 predictive cues before starting the learning phase. As previously mentioned, Experiment 1 was
18 conducted with nonmusicians as a sort of pure control group, who should normally have no
19 pitch identification (or sight-reading) skills in the absence of music training, but the pretests
20 allowed us to both (a) screen for undisclosed pre-existing knowledge and (b) to establish a
21 control for pre/post improvement scores. While we used both note positions and tones as

1 predictive cues for the multiple-cues group, only the tones preceded the note name in the tone-
 2 cue group. Therefore, both groups were presented with the tone naming task (Figure 2), in which
 3 they had to guess the name of the tone (no limit time; 21 trials). The note-position naming task
 4 (Figure 2), in which a music staff appeared in the center of the screen for 500 ms, then a note
 5 position appeared on the staff until participants responded (no limit time; 21 trials), was
 6 presented only in the multiple-cues group.

7 **Figure 3**

8 *Schematic description on the learning phase*



9

10 *Note.* On the top, an example of how the learning phase looked like for the multiple-cues group.
 11 On the bottom the learning phase for the tone-cue group.

12 Immediately after the pretest phase, participants started the learning phase that differed
 13 between the groups as shown in Figure 3. The multiple-cues group was presented, on each trial,
 14 with a musical staff that appeared on the screen for 500 ms. The note was then added to the staff
 15 and the tone started playing for 250 ms. The note name was then written inside the note and
 16 participants had 3000 ms to respond. After the note name was presented, the tone continued
 17 playing for another 500 ms (750 ms total) or until a response was made. Following correct
 18 responses, the next trial began immediately. If participants responded incorrectly or failed to
 19 respond in 3000 ms, the note name was replaced with “XXX” in red for 500 ms before the

1 beginning of the next trial. Globally, the same structure was also used for the tone-cue group,
 2 with a few exceptions: only the tone was presented as predictive cue (instead of both tone and
 3 note position), no musical staff was presented on the screen, and a fixation cross was presented
 4 in the center of the screen from the tone onset until it was replaced by the note name. In total,
 5 there were 420 trials in the learning phase, randomly ordered (without replacement), and a
 6 contingency manipulation of 90% (Schmidt et al., 2023) congruent pairings (e.g., the tone “fa”
 7 for the note name “fa”; high-contingency trials) and 10% incongruent trails (e.g., the tone “fa”
 8 for the note name “do”; low-contingency trials), as illustrated in Table 2. The congruency (or
 9 contingency learning) effect was measured as the difference in response times or error rates
 10 between low- and high- contingency trials.

11 **Table 2**

12 *Contingency manipulation*

13

Note Name	Tones						
	fa	sol	la	si	do	ré	mi
fa	54	1	1	1	1	1	1
sol	1	54	1	1	1	1	1
la	1	1	54	1	1	1	1
si	1	1	1	54	1	1	1
do	1	1	1	1	54	1	1
ré	1	1	1	1	1	54	1
mi	1	1	1	1	1	1	54

14

2

15 *Note.* In the table is represented the contingency proportion between high-contingency trials
 16 (presented 90% or 54 times) and low-contingency trials (presented 10% or 1 time each). For
 17 instance, the tone “fa” is presented much more often with the note name “fa” (high-
 18 contingency trials) than with the other note names (low-contingency trials).

19

20 Following the main learning phase, contingency awareness was collected to assess
 21 whether participants noticed the regularities during the learning phase. In particular, participants
 22 were assessed for *subjective awareness* (Cheesman & Merikle, 1984). For this, they responded
 23 to an on-screen instruction, where it was asked if they noticed that some pairings
 24 (high-contingency trials) were presented more often than others (low-contingency trials).

1 Participants could respond “yes” or “no” with a key press. This screen read (translated from
2 French):

3 *“During the third part of this experiment, note names were presented with a tone (or*
4 *with a tone and a note position for the multiple-cues group). Each tone was presented*
5 *more frequently with one note name than the others. That is to say, one tone was*
6 *frequently presented with “do,” another frequently with “re,” etc. Did you notice these*
7 *regularities?”*

8 Directly after, the posttest phase started and it was exactly the same as the pretest phase. This
9 allowed us to compare participants’ performance before and after the learning process. The
10 instructions for these phases were (translated from French):

11 *“Now, the task is similar, except that you will only hear a tone. Try to guess the name*
12 *of the tone by pressing the appropriate key on the keyboard.”*

13 A slightly different instruction was presented to the multiple-cues group (translated from
14 French):

15 *“Now, the task is similar, except that you will only see a note and hear a tone. Try to*
16 *guess the name of the note and the tone by pressing the appropriate key on the*
17 *keyboard.”*

18 **Data Analysis**

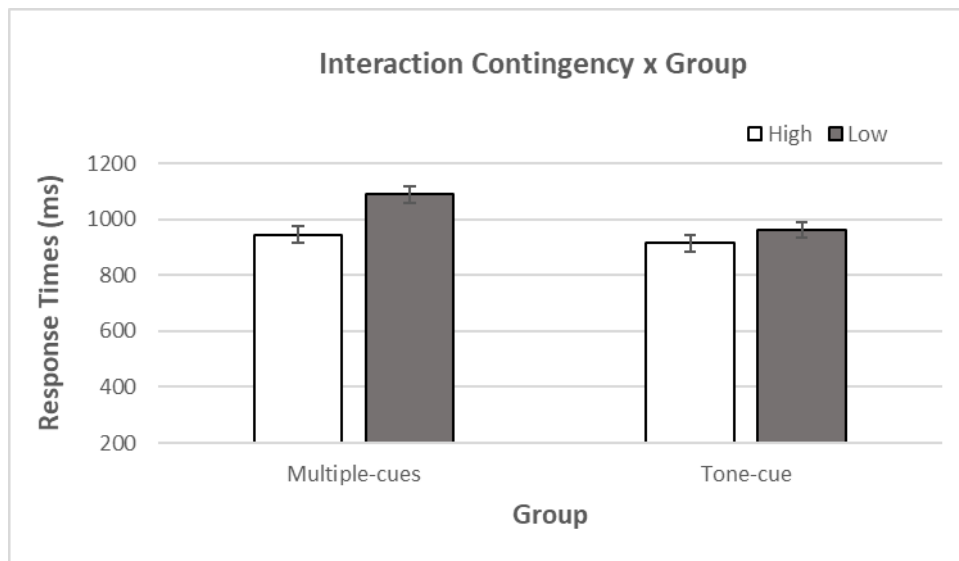
19 We conducted analyses on the learning and the test phases. For the learning phases, we
20 conducted a repeated measures ANOVA on correct RTs and error rates to assess the overall
21 main effects of contingency, group, and the interaction between them. Trials in which
22 participants failed to respond in 3000 ms (i.e., before the deadline) were eliminated (on average
23 on all the 119 participants, 12.54% of the trials were eliminated). For the test phases, we
24 analyzed accuracy rates to assess whether participants responded above chance (the chance

1 guessing rate was 1/7 or approximately 14.3%) and response times. All analyses were evaluated
2 at the $\alpha = .05$ level of significance. Additionally, we consistently reported the Bayes factor,
3 computed using JASP software (JASP, Team, 2019). We used the standard noninformative
4 Cauchy prior with a default width of 0.707. We report the Bayes factor BF_{10} , with values
5 between 3 and 10 supporting moderately strong evidence for the alternative hypothesis (H1;
6 Doorn et al., 2021). The data set is available via the following link: <https://osf.io/xjdt4/>.

7 **Results**

8 ***Response Times***

9 Response time results are presented in Figure 4. A repeated measures ANOVA for RTs with
10 the factors Contingency (high vs. low) and Group (multiple-cues group vs. tone-cue group)
11 indicated a significant main effect of Contingency, $F(1,114) = 74.0, p < .001, \eta^2 = .394, BF_{10}$
12 > 100 , showing faster responses for high-contingency trials ($M = 935\text{ms}, SD = 231$) than for
13 low-contingency trials ($M = 1027\text{ms}, SD = 224$). The main effect of Group was not significant,
14 $F(1,114) = 3.33, p = .071, \eta^2 = .028, BF_{10} = 1.18$. The interaction between Contingency and
15 Group was significant, $F(1,114) = 25.2, p < .001, \eta^2 = .181, BF_{10} > 100$, indicating a greater
16 difference between high and low contingency trials in the multiple-cues group ($M_{high_trials} =$
17 $946\text{ms}, SD = 257; M_{low_trials} = 1089\text{ms}, SD = 232$) compared to the tone-cue group ($M_{high_trials} =$
18 $925\text{ms}, SD = 202; M_{low_trials} = 962\text{ms}, SD = 199$). The contingency effect was significant for
19 both the multiple-cues group, $M_{low-high} = 143, SD = 139; t(58) = 7.92, p < .001, d = 1.03, BF_{10} >$
20 100 , and the tone-cue group, $M_{low-high} = 37.6, SD = 78.0; t(56) = 3.64, p < .001, d = .482, BF_{10}$
21 > 100 .

1 **Figure 4**2 *Interaction between contingency effect and Group in Experiment 1*

3

4 *Note.* Interaction between Contingency (High and Low) and Group (multiple-cues vs. tone-

5 cue), standard error bars are shown in the figure.

6 **Error Rates**

7 The repeated measures ANOVA for errors with the factors Contingency (high vs. low)

8 and Group (multiple-cues group vs. tone-cue group) revealed a significant main effect of

9 Contingency, $F(1,114) = 33.5, p < .001, \eta^2 = .227, BF_{10} > 100$, and a non-significant main effect

10 of Group, $F(1,114) = 3.38, p = .068, \eta^2 = .029, BF_{10} = 1.06$. The interaction between

11 Contingency and Group was also significant as shown in Figure 5, $F(1,114) = 12.5, p < .001, \eta^2$

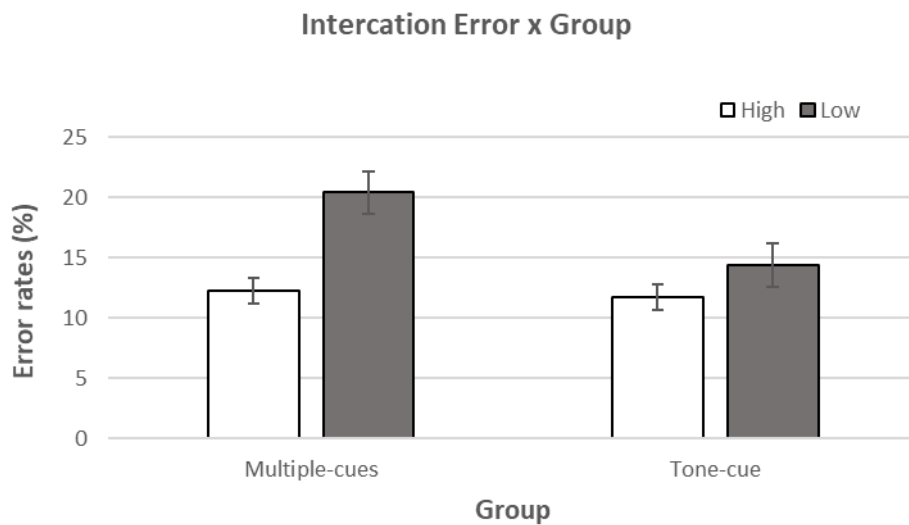
12 $= .099, BF_{10} = 43.84$ (multiple-cue group: $M_{high} = 12.3\%, SD = 8.24\%, M_{low} = 20.4\%, SD =$

13 13.2% ; tone-cue group: $M_{high} = 12.0\%, SD = 8.23\%, M_{low} = 13.9\%, SD = 13.4\%$). The

14 contingency effect was significant in the multiple-cues group, $M_{low-high} = 8.14\%, SD = 10.3\%$;

15 $t(58) = 6.05, p < .001, d = .788, BF_{10} > 100$, and not significant in the tone-cue group

16 $M_{low-high} = 1.96\%, SD = 5.16\%; t(56) = 1.78, p = .081, d = .236, BF_{10} = .631$.

1 **Figure 5**2 *Interaction between Error effect and Group in Experiment 1*

3

4 *Note.* Interaction between Error (High and Low) and Group (multiple-cues vs. tone-cue),
 5 standard error bars are shown in the figure.

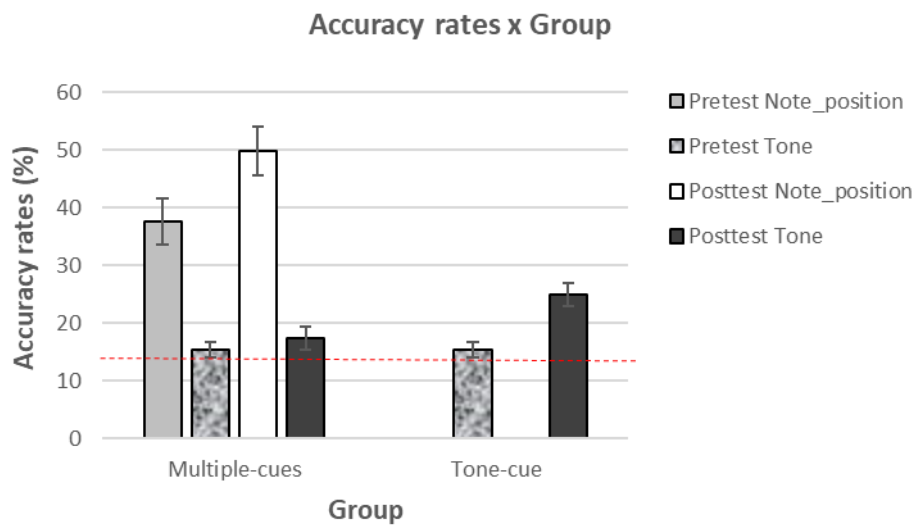
6 ***Pre/Posttest phases***

7 Here we report subjective awareness for the tone naming task. In the multiple-cues
 8 group, 67,80% (40 of 59) of the participants noticed the contingencies between note names and
 9 tones. In the tone-cue group, this percentage was 54,39% (31 of 57). The subjective awareness
 10 question concerning note positions was only posed to the multiple-cues group (i.e., as the tone-
 11 cue group did not see note positions). In the multiple-cues group, 60,40% (38 of 59) participants
 12 became aware of the contingencies between note names and note positions.

13 The *t*-tests for pretest and posttest accuracy, as shown in Figure 6, showed that in the
 14 note position naming task, the multiple-cues group performed well above chance (i.e., 14.3%)
 15 in both the pretest, $t(58) = 5.95$, $p < .001$, $d = .774$, $BF_{10} > 100$, $M = 37.6\%$, $SD = 30.1\%$, and
 16 posttest, $t(58) = 8.32$, $p < .001$, $d = 1.08$, $BF_{10} > 100$, $M = 49.8\%$, $SD = 32.8\%$. Further,
 17 performance was significantly improved in the posttest compared to pretest, $t(58) = 3.46$, $p =$
 18 $.001$, $d = .450$, $BF_{10} = 26.5$.

1 We then ran an ANOVA with the factors Test (pre vs. post) and Group (multiple-cues
2 vs. tone-cue) on the tone naming accuracy rates. The results showed a significant main effect
3 of Test, $F(1,114) = 15.49, p < .001, \eta^2 = .120, BF_{10} > 100$, indicating higher accuracy in naming
4 tones in posttest ($M = 21.1\%, SD = 15.0$) relative to pretest ($M = 15.4\%, SD = 10.1$). There was
5 also a weak significant main effect for Group, $F(1,114) = 4.30, p = .040, \eta^2 = .036, BF_{10} = 1.04$,
6 indicating higher overall accuracy in the tone-cue group than in the multiple-cues group. More
7 importantly, there was a significant interaction between Test and Group, $F(1,114) = 6.60, p =$
8 $.011, \eta^2 = .055, BF_{10} = 5.69$, indicating larger improvements in accuracy on posttest in the tone-
9 cue group ($M = 25\%, SD = 16.3$) relative to the multiple-cues group ($M = 17.4\%, SD = 12.7$), as
10 shown in Figure 6. The multiple-cues group did not perform significantly above chance in the
11 pretest, $t(58) = .824, p = .413, d = .107, BF_{10} = .197, M = 15.4\%, SD = 10.4\%$, and in the
12 posttest, $t(58) = 1.898, p = .063, d = .247, BF_{10} = .760, M = 17.4\%, SD = 12.7\%$. The tone-cue
13 group was also not significantly above chance in the pretest, $t(56) = .814, p = .419, d = .108,$
14 $BF_{10} = .198, M = 15.4\%, SD = 9.94\%$, but was significantly above chance in the posttest, $t(56)$
15 $= 4.94, p > .001, d = .654, BF_{10} > 100, M = 25.0\%, SD = 16.33\%$. More importantly, the data
16 showed a significant improvement between the pretest and posttest, $t(56) = 4.33, p > .001, d =$
17 $.574, BF_{10} > 100$, for the latter group.¹

¹ Given some violations of the normality assumptions of the ANOVAs, we also ran a non-parametric repeated measures ANOVA (Friedman test) on the tone naming accuracy (as suggested by an anonymous reviewer). Consistent with the above ANOVA results, no improvements between the pretest and posttest were observed for the multiple-cues group, $\chi^2 = .018, p = .893$. In contrast, a significant improvement between pretest and posttest was observed for the tone-cue group, $\chi^2 = 8.00, p = .005$.

1 **Figure 6**2 *Difference in Accuracy rates between Group in Experiment 1*

3

4 *Note.* Differences in Accuracy rates (pretest and posttest) between the groups (multiple-cues
5 vs. tone-cue). Standard error bars and accuracy chance guessing at 14.3% (in red) are shown
6 in the figure.

7 Furthermore, the ANOVA with the factors Test (pre vs. post) and Group (multiple-cues
8 vs. tone-cue) on the RTs in the tone naming task, showed a main significant effect of Test,
9 $F(1,114) = 8.435, p < .004, \eta^2 = .069, BF_{10} = 7.049$, indicating that participants were overall
10 slower in naming tones in the pretest ($M = 2296$ ms, $SD = 1795$) compared to the posttest ($M =$
11 1796 ms, $SD = 1603$). Both the main effect for Group, $F(1,114) = .386, p = .536, \eta^2 = .003,$
12 $BF_{10} = .244$, and the interaction between Test and Group, $F(1,114) = .262, p = .610, \eta^2 = .002,$
13 $BF_{10} = .227$, were not significant.

14 Overall, while a significant improvement was found between the pretest and the posttest
15 rates in the tone-cue group, the same effect was not observed in the multiple-cues group,
16 potentially indicating an overshadowing effect.

17 **Discussion**

18 In Experiment 1, we wanted to study whether nonmusicians were able to easily and
19 rapidly learn pitch-label associations. Our results showed that, as expected, both groups of

1 participants showed a contingency effect in the learning phase. We note that while contingency
2 effects were larger in the multiple-cues group in both response times and errors, this finding
3 should be interpreted with caution, as the multiple-cues group could be biased not only by the
4 tones, but also by the predictive note positions. Also interesting, both groups were able to
5 respond above chance in the tests phases in line with previous findings in the contingency
6 learning literature (Iorio et al., 2023; Schmidt & De Houwer, 2019) and overall they
7 significantly decreased their RTs in the posttest compared to the pretest. However, participants
8 in the multiple-cues group seemed to show worse performance compared to the tone-cue group.
9 Therefore, although previous research seems to suggest that presenting both note position and
10 tones can benefit the learning of sub-skills (Mishra, 2014), our results suggest that when it
11 comes to pitch identification presenting more than one predictive cue may interfere with the
12 acquisition between the note name and the tone (i.e., an overshadowing effect).

13

Experiment 2

14 In Experiment 1, we studied the more experimentally “pure” case of nonmusicians
15 learning to identify note pitches who, incidentally, have also clearly “missed” any potential
16 critical period for acquiring pitch identification skills (see Introduction). This sort of sample
17 would also correspond to novice musicians just beginning to learn music. Learning to improve
18 pitch identification skills could also be useful for experienced musicians. In that vein,
19 Experiment 2 studies whether our incidental learning procedure can help musicians to improve
20 their ability to identify and label tones. Incidentally, musicians are also an interesting group to
21 study for another reason. Our participants were musicians but AP non-possessors. If pitch
22 identification skills are strictly dependent on “good genes” (see Introduction), then this group
23 seems to be the most unlikely to have said genes: they have had more than enough experience
24 seeing music notation, playing notes, and hearing the corresponding pitches to have acquired
25 AP already if they had the right disposition for it. Since previous research has suggested that

1 AP development is related to early musical training (Crozier, 1997; Deutsch et al., 2006;
2 Miyazaki & Ogawa, 2006), we also decided to take this measure into account as a covariate in
3 our analysis.

4 As a further manipulation in Experiment 2, we introduced a second name-to-key
5 mapping to be able to test for spatial compatibility effects. Specifically, Rusconi et al. (2006)
6 suggested that the human cognitive system automatically codes pitches spatially with the
7 highest pitches represented on the right and the lowest pitches on the left (akin the Spatial
8 Musical Association of Response Codes, SMARC effect) and recent research indicates that
9 space-pitch associations exhibit greater stability when supplemented with metaphors embedded
10 in language (Dolscheid et al., 2020). The French language, for instance, expresses pitch
11 predominantly in terms of spatial height. In Experiment 1, the lowest note name for the lowest
12 pitch in our task, “fa”, corresponded to the leftmost key on the keyboard, “Z”. Possibly, this
13 could help with the acquisition of key-label responses based on the research on the SMARC
14 effect. As a small note, we did not find evidence for a SMARC effect on the acquisition of the
15 note name/note position associations in our previous work (Iorio et al., 2023). However, to
16 control for possible influence of the SMARC effect in our paradigm, we compared performance
17 in two groups (compatible vs. incompatible groups, see the *Method* section for more details).

18 Our primary hypothesis for the present experiment was that musicians would be able to
19 improve their pitch identification, similar to the nonmusicians in Experiment 1. Given that the
20 tone-cue manipulation improved posttest note detection notably more than the multiple-cues
21 manipulation in Experiment 1, we dropped the multiple-cues condition from Experiment 2.
22 Additionally, we hypothesized that pitch identification abilities would be higher for participants
23 that started learning music earlier on in life. To what extent early music learning might interact
24 with pre/post improvement scores was uncertain.

1 **Method**

2 *Participants*

3 The recruitment process was similar to the one used in Experiment 1, except that we
4 searched for musicians rather than nonmusicians. Therefore, as specified in the recruitment
5 advertisement, we looked for French speaking participants with experience in playing music.
6 117 participants took part in the experiment and received monetary compensation (3.80 £) for
7 their participation. However, 9 participants were excluded from the analysis because they failed
8 to report information about the age they started musical training, information that we used as a
9 covariate in the following analyses. Of the remaining 108 participants, 19 declared to have
10 absolute pitch. However, only seven participants reported accuracy rates between 60% and
11 100% in the pretest and were discarded from the following analysis, as in Experiment 1. All
12 participants accepted a written consent before beginning the study. All the procedures were
13 conducted in accordance with the Declaration of Helsinki. Participants' anonymization was
14 guaranteed.

15 *Apparatus, Design, and Procedure*

16 The general structure of the experiment was similar to the one used in Experiment 1
17 with some exceptions. Firstly, we changed the name-to-key assignment (the keys D, F, G, H, J,
18 K, L, instead of the keys Z,E,R,T,Y,U,I) to control for possible differences in the keyboards
19 used by the participants recruited online. As mentioned above, we introduced a second name-
20 to-key mapping to be able to test for spatial compatibility effects. For the first group (compatible
21 group), we used the same name-to-key assignment as for Experiment 1 (i.e., the tones used went
22 from “fa” to “mi”, corresponding to the D to L keys on the keyboard). In this group, the spatial
23 position of the tones was “compatible”, or in other words matched, the responses. For the second
24 group (incompatible group), we used the D to L keys to refers to “do” to “si” note names. In
25 this group, there was no spatial compatibility between the tones and the responses (e.g., the

1 leftmost “D” key corresponded to one of the highest tones, viz., “do”). As one further change,
2 we excluded the multiple-cues condition. All participants completed the tone-cue condition
3 from Experiment 1.

4 ***Data analysis***

5 As in Experiment 1, we ran an ANOVA on RTs and error rates for the learning phase
6 and t-tests on accuracy and RTs for the test phases. However, here we additionally added
7 information about the start of musical training as a covariate in our analysis. 12.77% of the trials
8 on the total number of participants were eliminated based on the same criteria used in
9 Experiment1 (i.e., trials in which participants failed to respond in 3000 ms). All analyses were
10 evaluated at the $\alpha = .05$ level of significance, and we reported the Bayes factor. The data set is
11 available via the following link: : <https://osf.io/xjdt4/>.

12 **Results**

13 ***Response Times***

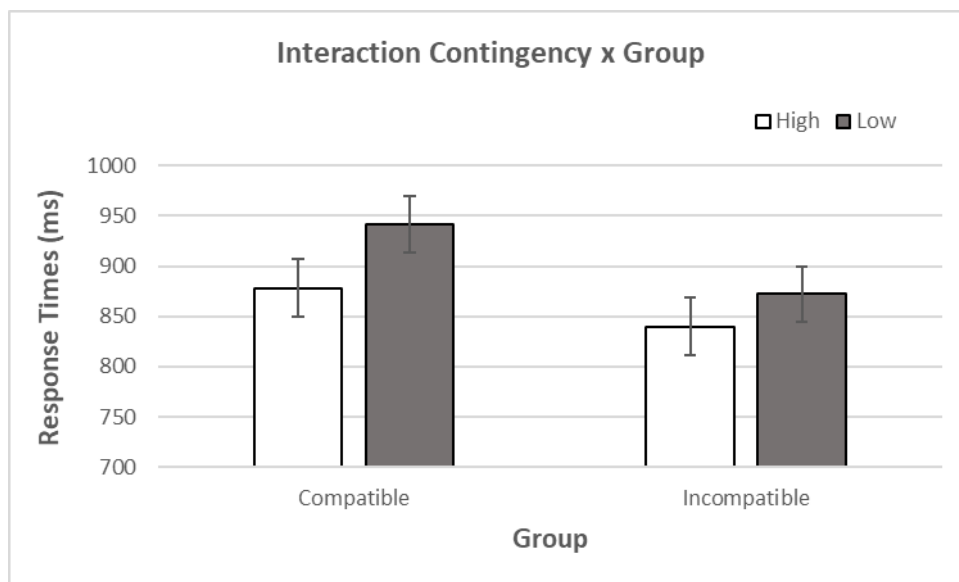
14 The repeated measures ANOVA for RTs with the factors Contingency (high vs. low)
15 and Group (compatible vs. incompatible) and the age of the start of musical training as covariate
16 showed a significant main effect of Contingency, $F(1,98) = 36.97, p < .001, \eta^2 = .274, BF_{10} >$
17 100 , indicating faster responses for high-contingency trials ($M = 860\text{ms}, SD = 209$) than for
18 low-contingency trials ($M = 909\text{ms}, SD = 221$). The main effect of Group was not significant,
19 $F(1,98) = 1.59, p = .210, \eta^2 = .016, BF_{10} = .702$. The interaction between Contingency and Group
20 was significant (Figure 7), $F(1,98) = 4.12, p = .045, \eta^2 = .040, BF_{10} = 1.02$, due to a greater
21 difference between high and low contingency trials for the compatible group ($M_{\text{high-contingency}} =$
22 $878\text{ms}, SD = 214, M_{\text{low-contingency trials}} = 942\text{ms}, SD = 227$) compared to the incompatible group:
23 ($M_{\text{high-contingency}} = 840\text{ms}, SD = 204, M_{\text{low-contingency trials}} = 872\text{ms}, SD = 210$).

24 The contingency effect was significant for both the compatible group, $M_{\text{low-high}} = 63.7,$
25 $SD = 86.6; t(52) = 5.36, p < .001, d = .736, BF_{10} > 100$, and the incompatible group, $M_{\text{low-high}} =$

1 32.5, $SD = 70.2$; $t(47) = 3.21$, $p = .002$, $d = .436$, $BF_{10} = 13.1$.² The interaction between
 2 Contingency and beginning of the musical training was not significant, $F(1,98) = .621$, $p = .433$,
 3 $\eta^2 = .006$, $BF_{10} = .301$.

4 **Figure 7**

5 *Interaction between contingency effect and Group in Experiment 2*



6
 7 *Note.* Interaction between Contingency (High and Low) and Group (compatible vs.
 8 incompatible), standard error bars are shown in the figure.

9 **Error Rates**

10 The repeated measures ANOVA for errors with the factors Contingency (high vs. low)
 11 and Group (compatible vs. incompatible) revealed a main effect of Contingency, $F(1,99) =$
 12 17.51 , $p < .001$, $\eta^2 = .150$, $BF_{10} > 100$ (more errors for low trials $M = 15.3\%$, $SD = 11.8$,
 13 compared to high trials $M = 12.5\%$, $SD = 9.75$), and a non-significant main effect for Group,
 14 $F(1,99) = 1.27$, $p = .263$, $\eta^2 = .013$, $BF_{10} = .573$. The interaction between Contingency and
 15 Group was also not significant, $F(1,99) = 1.27$, $p = .262$, $\eta^2 = .013$, $BF_{10} = .382$.

² An anonymous reviewer suggested that the compatibility effect might be particularly present for pianists, where the left-to-right assignment of pitches to keys is particularly salient. To explore this possibility, we separated participants into two groups: those who reported studying piano ($n = 37$) and those who reported studying an instrument other than piano or singing ($n = 64$). In an ANOVA including this extra factor, the main effect of Contingency remained significant, $F(1,97) = 35.55$, $p < .001$, $\eta^2 = .268$. The main effect of Group, $F(1,97) = 10.9$, $p = .298$, $\eta^2 = .0011$, and Instrument played, $F(1,97) = 1.17$, $p = .282$, $\eta^2 = .012$, were not significant. Most critically, the interaction between Contingency x Group x Instrument played was not significant, $F(1,97) = 1.31$, $p = .254$, $\eta^2 = .013$, though we do note that there was at least a numerical trend for a larger Contingency by Group interaction for piano players (55 ms interaction; compatible group: $M_{high-contingency} = 826$ ms, $SD = 168$, $M_{low-contingency} = 904$ ms, $SD = 182$; incompatible group: $M_{high-contingency} = 829$ ms, $SD = 191$, $M_{low-contingency} = 852$ ms, $SD = 197$) relative to other instrument players (17 ms interaction; compatible group: $M_{high-contingency} = 905$ ms, $SD = 232$, $M_{low-contingency} = 961$ ms, $SD = 247$; incompatible group: $M_{high-contingency} = 847$ ms, $SD = 215$, $M_{low-contingency} = 886$ ms, $SD = 220$).

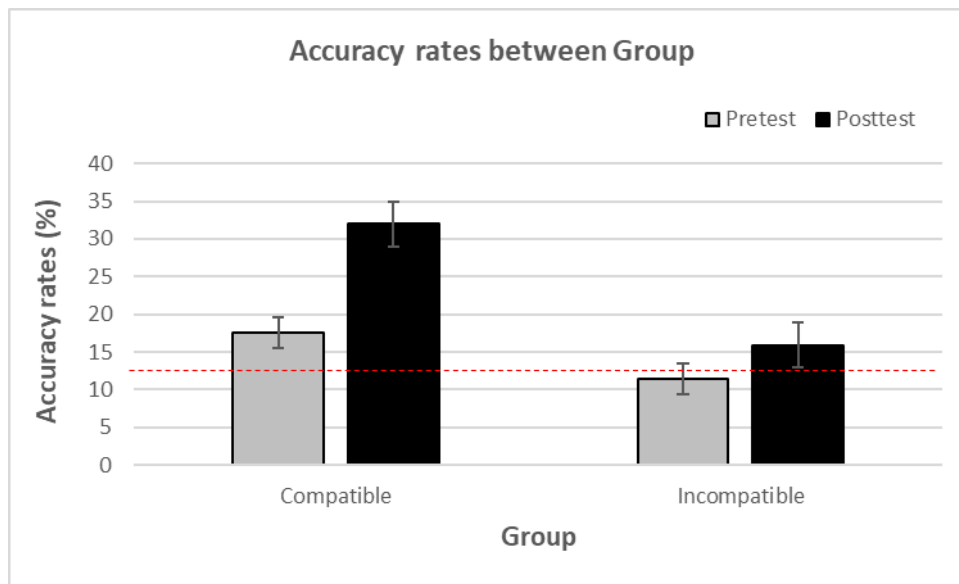
1 **Test phases**

2 71.29% of participants (77 of 108) noticed the contingencies between the tones and the
 3 note names. We the performed an ANOVA on the accuracy rates with Test (pre vs. post) and
 4 Group (compatible vs. incompatible) as factors. The main effect of Test was significant, $F(1,99)$
 5 $= 27.80$, $p < .001$, $\eta^2 = .219$, $BF_{10} > 100$, as well as the main effect of Group, $F(1,99) = 17.4$, p
 6 $< .001$, $\eta^2 = .150$, $BF_{10} > 100$. Also the interaction Test x Group was significant, $F(1,99) = 7.70$,
 7 $p = .007$, $\eta^2 = .072$, $BF_{10} = 5.98$ (pre-test: $M_{compatible} = 17.6\%$, $SD = 14.5$; $M_{incompatible} = 11.4\%$
 8 $SD = 10.1$. post-test: $M_{compatible} = 32.0\%$, $SD = 23.1$; $M_{incompatible} = 15.9\%$ $SD = 13.0$).

9 T-tests for pretest and posttest accuracy rates, shown in Figure 8, revealed that the
 10 compatible group did not perform significantly above chance (i.e., 14.3%) in the pretest, $t(52)$
 11 $= 1.66$, $p = .104$, $d = .228$, $BF_{10} = .537$, $M = 17.6\%$, $SD = 14.5$, but were significantly above
 12 chance in the posttest, $t(52) = 5.58$, $p < .001$, $d = .766$, $BF_{10} > 100$, $M = 32.0\%$, $SD = 23.1$. The
 13 improvement between pre/posttest was significant for this group $t(52) = 5.01$, $p > .001$, $d =$
 14 $.688$, $BF_{10} > 100$.

15 The incompatible group did not perform above chance in the pretest, $t(47) = -1.974$, p
 16 $= .054$, $d = -.285$, $BF_{10} = .930$, $M = 11.4\%$, $SD = 10.1$, and in the posttest, $t(47) = .835$, $p = .408$,
 17 $d = .121$, $BF_{10} = .218$, $M = 15.9\%$, $SD = 13.0$. Although the incompatible group reported
 18 performance slightly below chance guessing in the pretest, their performance significantly
 19 improved between pre/posttest, $t(48) = 2.22$, $p = .031$, $d = .320$, $BF_{10} = 1.45$.³

³ Again, we ran a non-parametric repeated measures ANOVA (Friedman test) on the tone naming accuracy. The improvement from pretest to posttest was significant in the compatible group, $\chi^2 = 16.5$, $p < .001$. For the incompatible group, the improvement was not significant, $\chi^2 = .641$, $p = .423$.

1 **Figure 8**2 *Difference in Accuracy rates between Group in Experiment 2*

3

4 *Note.* Differences in Accuracy rates (Pretest and Posttest) between the groups (compatible vs.
 5 incompatible), standard error bars and accuracy chance guessing at 14.3% are shown in the
 6 figure.

7 We ran an ANOVA with the factors Test (pre vs. post) and Group (compatible vs.
 8 incompatible) on the RTs for the tone naming task. This analysis showed a nonsignificant main
 9 effect for Test, $F(1,99) = 3.834, p = .053, \eta^2 = .037, BF_{10} = 1.147$, a nonsignificant main effect
 10 of Group, $F(1,99) = .002, p = .959, \eta^2 = .000, BF_{10} = .175$, and a non-significant interaction
 11 between Test and Group, $F(1,99) = .353, p = .554, \eta^2 = .003, BF_{10} = .258$.

12 **Discussion**

13 In Experiment 2, we wanted to determine whether our incidental learning procedure
 14 could help musicians to improve their ability to identify and label tones. The results showed a
 15 significant contingency effect for both groups in response times and errors. However, our
 16 findings on the RTs in the test phases did not reveal any general significant improvement in
 17 response times between the pre- and posttest. Furthermore, only the compatible group
 18 performed significantly above chance in the posttest, though both groups showed an increase in
 19 performance between the pre- and posttest. Similarly, the RT contingency effect was larger in

1 the compatible group. These outcomes suggest that when asked to explicitly name a tone,
2 participants may rely on some sort of internal spatially related code for tones, as shown in
3 previous research (Ariga & Saito, 2019; Rusconi et al., 2006). Participants can learn the
4 contingencies in either case, but spatial compatibility may help.

5 **Experiment 3**

6 In Experiment 3, we extend the results of the preceding experiments in two ways. First,
7 we tested whether pitch learning persists over time. Considering how previous research about
8 pitch identification describes the acquisition of pitch-label associations as something difficult,
9 it might be the case that the learning effect we have shown in the Experiment 1 is just temporary
10 and will not persist over time. That is, what if nonmusicians were able to learn the pitch-label
11 associations as a result of the many repetitions they were exposed to, but they did not form any
12 long-lasting representations of these associations in memory? Here we argue that pitch-label
13 associations can not only be incidentally learned, but that the information is retained in memory
14 and it can be easily retrieved not only immediately after learning it, but even more interestingly
15 after some time from the learning process. We therefore hypothesized that posttest scores would
16 still be increased after a delay (i.e., that the learned pitch information remains in memory).

17 Second, we aimed to study the effect of intentionality on the learning and consolidation
18 of pitch-label associations. Past research suggests that being aware of the contingencies before
19 beginning the experiment benefits their acquisition (Schmidt & De Houwer, 2012b, 2012a,
20 2012c). That is, while participants who are not informed about the regularities in the task
21 generally still learn said regularities, participants informed in advance about the contingency
22 manipulation often show even larger learning effects. Similar results have also been observed
23 in sequence learning studies (Destrebecqz, 2004). This instruction effect is often only moderate
24 and is not always robust. For instance, in the above-mentioned sight-reading studies (Iorio et
25 al., 2023) we did not find any significant differences in the learning phase between participants

1 that were aware of the contingencies and those that incidentally learned them. Numerical
2 differences were suggestive, however, and posttest ratings were improved with explicit
3 instruction. To assess this question in the pitch learning context, we therefore created two
4 groups: an incidental learning group that was not informed about the manipulation before
5 starting the experiment and a deliberate learning group that was. We expected larger learning
6 effects in the deliberate learning group relative to the incidental learning group, both in the
7 performance measures during the learning phase and in the posttest scores. That is, it is possible
8 that being attentive to the contingencies helps with consolidation more than learning in a purely
9 incidental way.

10 **Method**

11 *Participants*

12 268 students from the University of Burgundy took part in this experiment. The
13 experiment was part of a second-year cognitive psychology tutorial and served as the basis for
14 student presentations. Students were not informed about the purpose of the experiment until
15 after completing both phases, however. Due to complications with the COVID pandemic, the
16 study was also conducted online using the same software as the preceding experiments
17 (Psytoolkit; Stoet, 2010, 2016). We excluded participants that either did not complete all the
18 test phases or did not correctly indicate their student number (which did not allow us to match
19 their datasets together). 136 participants that met these conditions and declared to not have AP
20 were randomly divided into an incidental learning group (73 in total) and a deliberate group (63
21 in total). One participant was removed from the sample because accuracy was between 60%
22 and 100% in the pretest. As in the previous studies, all participants signed a consent form before
23 starting the study. The study was consistent with the Declaration of Helsinki and participants'
24 anonymization was guaranteed.

1 *Apparatus, Design, and Procedure*

2 The experiment followed the same structure as the previous studies with some
3 exceptions. First, the participants were divided into incidental and deliberate learning groups.
4 While in the first group participants were not instructed about the contingencies (i.e., as in the
5 prior experiments), in the deliberate group participants were told about the contingencies before
6 beginning the experiment and they were encouraged to learn them, translated from French:

7 *“Note: Each note will be presented more frequently with the correct tone and less*
8 *frequently with the incorrect tones. Try to learn the note name for each tone.”*

9 As an additional change, in order to study the consolidation of new material, we also
10 added a (surprise) follow up session one week after the end of the learning phase. During the
11 follow up, participants were asked to take part in a second posttest tone naming task, which was
12 identical in all respects to the other posttest (and pretest). As a minor aside, we note that students
13 were also asked to fill in a paper-and-pencil survey with various questions about their prior
14 music experiences. We note that this survey was included for purely pedagogical purposes, and
15 we have not nor had ever intended to analyze these data, with some exceptions for the questions
16 used for controlling for musical expertise mentioned below.⁴

17 *Data analysis*

18 The analysis was based on the same criteria as those used in Experiments 1 and 2. We
19 conducted a repeated measures ANOVA for RTs with musical expertise as a covariate and for
20 error rates to assess the overall main effects of Contingency, Group, and the interaction between
21 them. Following the exclusion criteria used in Experiments 1 and 2, we discarded 13.37% of

⁴ In fact, the surveys were printed the prior year for an unrelated study and had not been used due to the COVID pandemic (an electronic version was used instead). We decided to use these questionnaires both (a) because they contained a few questions related to our selection criteria, and (b) to give students inspiration for potential discussion points in their group presentations. The non-pertinent questions, however, have not been coded electronically.

1 the data. We ran t -tests and ANOVAs on Accuracy and RTs for the test phases and the follow
2 up. All analyses were evaluated at the $\alpha = .05$ level of significance. Again, the Bayes factor was
3 reported for each analysis. The data set is available via the following link: <https://osf.io/xjdt4/>.

4 **Results**

5 ***Response Times***

6 We ran a repeated measures ANOVA for RTs with the factors Contingency (high vs.
7 low) and Group (incidental vs. deliberate) that indicated a significant main effect of
8 Contingency, $F(1,133) = 13.75, p < .001, \eta^2 = .094, BF_{10} = 45.26$, showing faster responses for
9 high-contingency trials ($M = 933\text{ms}, SD = 164$) than for low-contingency trials ($M = 963\text{ms},$
10 $SD = 171$). The main effect of Group was not significant, $F(1,133) = .661, p = .418, \eta^2 = .005,$
11 $BF_{10} = .459$. The interaction between Contingency and Group was not significant,
12 $F(1,133) = 2.20, p = .140, \eta^2 = .016, BF_{10} = .489$, though there was a numerical trend towards a
13 larger contingency effect for the deliberate learning group, $M_{\text{low-high contingency trials}} = 43.2, SD =$
14 111 , compared to the incidental group, $M_{\text{low-high contingency trials}} = 18.5, SD = 81.3$.

15 ***Error Rates***

16 A repeated measures ANOVA for errors with the factors Contingency (high vs. low)
17 and Group (incidental and deliberate) revealed a significant main effect of Contingency,
18 $F(1,133) = 16.74, p < .001, \eta^2 = .112, BF_{10} > 100$, showing more errors for low-contingency
19 trials ($M = 15.4\%, SD = 10.9$) than for high-contingency trials ($M = 13.1\%, SD = 8.48$). The main
20 effect of Group, $F(1,133) = .291, p = .590, \eta^2 = .002, BF_{10} = .367$, and the interaction between
21 Contingency and Group, $F(1,133) = .040, p = .840, \eta^2 = .000, BF_{10} = .185$, were not significant
22 (incidental group, $M_{\text{high-trials}} = 12.8\%, SD = 7.47, M_{\text{low-trials}} = 15.0\%, SD = 9.53$; deliberate group,
23 $M_{\text{high-trials}} = 13.5\%, SD = 9.59, M_{\text{low-trials}} = 16.0\%, SD = 12.3$).

1 *Test phases*

2 For the subjective awareness question, 59.25% (80 of 135) of the participants noticed
 3 the contingencies between tones and note names. The incidental learning group performed
 4 significantly above chance in the pretest, $t(72) = 2.29$, $p = .025$, $d = .268$, $BF_{10} = 1.49$,
 5 $M=17.4\%$, $SD = 11.4$, in the posttest, $t(72) = 8.22$, $p < .001$, $d = .962$, $BF_{10} > 100$, $M=29.9\%$,
 6 $SD = 16.2$, and in the follow up, $t(72) = 4.54$, $p < .001$, $d = .531$, $BF_{10} > 100$, $M=22.6\%$, $SD =$
 7 15.7 . For the deliberate group, performance was not significantly above chance in the pretest,
 8 $t(61) = 1.50$, $p = .139$, $d = .191$, $BF_{10} = .402$, $M=17.0\%$, $SD = 14.0$, but was significant in the
 9 posttest, $t(61) = 6.75$, $p < .001$, $d = .857$, $BF_{10} > 100$, $M=30.3\%$, $SD = 18.7$, and in the follow
 10 up, $t(61) = 5.68$, $p < .001$, $d = .721$, $BF_{10} > 100$, $M=28.7\%$, $SD = 20.0$. The differences in
 11 accuracy rates found between the groups were not significant in the pretest, $t(133) = .173$, $p =$
 12 $.863$, $d = .029$, $BF_{10} = .187$, or in the posttest, $t(133) = -.154$, $p = .878$, $d = -.026$, $BF_{10} = .187$,
 13 however the deliberate group performed significantly better than the incidental group in the
 14 follow up, $t(133) = 1.981$, $p = .0496$, $d = .342$, $BF_{10} = 1.091$.

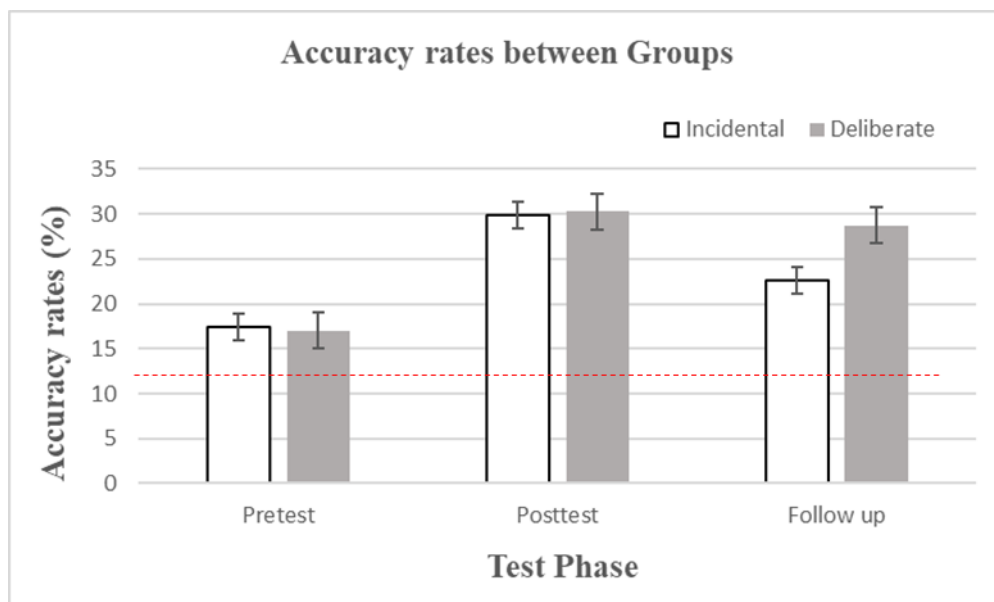
15 We performed an ANOVA⁵ on the accuracy rates with Test (pre vs. post) and Group
 16 (deliberate vs. incidental) as factors. The main effect of Test was significant, $F(2,266) = 41.49$,
 17 $p < .001$, $\eta^2 = .238$, $BF_{10} > 100$. The main effect of Group was not significant, $F(1,133) = .852$,
 18 $p = .358$, $\eta^2 = .006$, $BF_{10} = .260$. The interaction Test x Group was also not significant, $F(2,266)$
 19 $= 2.96$, $p = .053$, $\eta^2 = .022$, $BF_{10} = .710$ (pre-test: $M_{incidental} = 17.4\%$, $SD= 11.4$; $M_{deliberate} =$
 20 17.0% $SD=14.0$; post-test: $M_{incidental} = 29.9\%$, $SD= 16.2$; $M_{deliberate} = 30.3\%$ $SD=18.7$; follow
 21 up: $M_{incidental} = 22.6\%$, $SD= 15.7$; $M_{deliberate} = 28.7\%$ $SD=20.0$).

⁵ Non-parametric repeated measures ANOVAs (Friedman test) on the accuracy rates revealed significant improvement from pretest to posttest in the incidental, $\chi^2 = 16.0$, $p < .001$, and deliberate group, $\chi^2 = 19.8$, $p < .001$. The difference between pretest and follow up was also significant for the incidental, $\chi^2 = 8.14$, $p = .004$, and deliberate group, $\chi^2 = 11.0$, $p < .001$. Finally, the decrease between posttest and follow up was significant for the incidental group, $\chi^2 = 7.56$, $p < .006$, but not for the deliberate group, $\chi^2 = .276$, $p = .599$.

1 Accuracy rates were significantly higher in posttest compared to pretest in both groups,
 2 as shown in Figure 9: incidental group, $t(72) = 5.99, p < .001, d = .701, BF_{10} > 100$, deliberate
 3 group, $t(61) = 5.95, p < .001, d = .711, BF_{10} > 100$. Accuracy rates were significantly lower in
 4 the follow-up compared to the posttest in the incidental group, $t(72) = -4.34, p < .001, d = -$
 5 $.508, BF_{10} > 100$, and not significantly different for the deliberate group, $t(61) = .806, p = .423,$
 6 $d = .102, BF_{10} .190$. Most importantly, accuracy rates were significantly higher in the follow
 7 up compared to the pretest for both groups: incidental group, $t(72) = 3.12, p = .003, d = .365,$
 8 $BF_{10} = 10.6$, and deliberate group, $t(61) = 4.84, p < .001, d = .615, BF_{10} > 100$.

9 **Figure 9**

10 *Difference in Accuracy rates between Group in Experiment 3*



11
 12 *Note.* Differences in Accuracy rates (Pretest, Posttest and Follow-up) between the groups
 13 (Incidental vs. Deliberate), standard error bars and accuracy chance guessing at 14.3% are
 14 shown in the figure.

15 In the ANOVA with the factors of Test (pre and post) and Group (incidental and
 16 deliberate) on response times, while the main effect of Test was significant, $F(2,266) = 10.86,$
 17 $p < .001, \eta^2 = .076, BF_{10} > 100$, showing a decrease in response times between the tests (M_{pretest}
 18 $= 2686$ ms, $SD = 3081$; $M_{\text{posttest}} = 1816$ ms, $SD = 1223$; $M_{\text{follow up}} = 1677$ ms, $SD = 1016$), both the

1 overshadowing effect. That is, if two stimuli, A and X (or in this specific case, the note position
2 and the tone), are presented together and are followed by an outcome (the note name in our
3 study), learning about the relation between X and the outcome is often weaker compared to
4 when only stimulus X is paired with the outcome (Kamin, 1969; I. Pavlov P., 1927). The data
5 are thus consistent with overshadowing, given that the multiple-cues group performed more
6 poorly than the tone-cue group. Furthermore, these results seem to be inconsistent with the idea
7 that combining auditory and visual information boosts musical learning, as previously
8 suggested in a sight-reading context (see Mishra, 2014 for a review). Of course, there are both
9 auditory and visual information that are important to learn in music learning, but combining the
10 two into one learning procedure may be suboptimal. We briefly note that there are several
11 competing theories of overshadowing and other cue competition phenomena. For instance, the
12 Rescorla-Wagner (1972) model suggests that learning of one association (e.g., between pitches
13 and note names in the current experiment) is impaired to the extent that another association
14 (e.g., between note positions and note names) is strong enough to anticipate the outcome (e.g.,
15 note name), at which point associations are less strongly updated. According to another view
16 (Mackintosh, 1975), attention is drawn to a more salient stimulus (e.g., note positions) which
17 reduces learning for the “overshadowed” stimulus (e.g., pitches). Regardless of the exact
18 mechanism, our results suggest that presenting musical notation does not *help* with learning to
19 identify pitches by ear.

20 In Experiment 2, we further investigated the efficacy of an incidental learning procedure
21 in improving pitch identification in participants with previous musical experience. Similar to
22 the results for nonmusicians, musicians were also able to strengthen their knowledge about
23 pitch-label associations and use this information to correctly guess above chance the name of
24 the tones in the posttest tone naming task. In addition, in Experiment 2 we controlled for the
25 possible influence of the SMARC effect (Ariga & Saito, 2019; Rusconi et al., 2006) on pitch-

1 label acquisition. In the compatible group, tones were spatially congruent with the position of
2 the keys on the keyboard, whereas in the incompatible group the leftmost tone “mi” was mapped
3 to one of the rightmost keys on the keyboard. Surprisingly, the incompatible group responded
4 faster than the compatible group in the learning phase. The reason for this is unclear but might
5 be related to the fact that the response keys for the incompatible group were ordered from “do”
6 to “si”, a more “classical” order of the note names (i.e., the order that most learn in elementary
7 school). This may have facilitated overall RTs. However, spatial compatibility did influence
8 test phase performance in the anticipated direction. Accuracy in the compatible group improved
9 significantly from pre- to post-test, but this improvement was much smaller in the incompatible
10 group. This latter result is coherent with the notion that we spatially code pitches (Ariga &
11 Saito, 2019; Rusconi et al., 2006): the incongruency between pitches and the spatial location in
12 the incompatible group may have interfered with the more natural codes and therefore
13 negatively influenced the acquisition of the pitch-label associations. Pitch learning clearly
14 occurred (i.e., given the pre-post improvements), but spatial incompatibility seems to make this
15 learning more difficult.

16 In Experiment 2, we also measured the age at which participants began musical training,
17 which previous research suggests may have an impact on the internalization of pitches (Crozier,
18 1997; Deutsch et al., 2006; Miyazaki & Ogawa, 2006). Surprisingly, our results did not reveal
19 any influence of this factor on the contingency effect (i.e., age of beginning music training did
20 not interact with contingency). On the contrary, these results seem to point to the idea that even
21 those who started musical training later than the critical period (i.e., between 4 and 5 years old)
22 can still improve their performance in the auditory domain, suggesting the presence of a
23 changeable internal pitch representation rather than a stable “pitch template”.

24 Finally, in Experiment 3 we focused on studying the role of incidental learning in the
25 acquisition and consolidation of pitch-label associations in longer-term memory. Once again,

1 as already reported in Experiment 1, nonmusicians showed significant contingency effects in
2 both an incidental and a deliberate learning group. However, no notable differences were
3 observed in the size of these learning effects, suggesting that being aware of the contingencies
4 does not necessarily help to learn them better in performance tasks (or at least not to a substantial
5 degree). On the other hand, we did find some differences in performance between the two
6 groups in the test phases. The deliberate group not only reported higher accuracy rates (although
7 the difference in accuracy rates between the groups was not significant) in the posttest compared
8 to the incidental group, they also performed better in the follow up. In line with previous
9 research (Iorio et al., 2023; Schmidt & De Houwer, 2012c), these results may indicate that being
10 attentive to the contingencies benefits the consolidation of the information acquired. However,
11 when it comes to skill automatization (e.g., as measured by RTs and error rates), it seems that
12 intentionality does not positively increase performance substantially.

13 **Limitations and Future Directions**

14 It is important to reiterate that the goals of the present work diverge from those of past
15 work on pitch identification learning and, more particularly, learning of AP. As mentioned in
16 the Introduction, much work on this topic has focused on the determinants of absolute pitch,
17 with both genetic factors and early music learning being indicated as key factors. Some debate
18 has raged about whether absolute pitch (i.e., to a strict criterion) is learnable at all in the absence
19 of early music training and/or the right genetic background. Although some studies have
20 certainly indicated that improvements are possible with extended, focal training regimes, doubt
21 persists as to whether it would be possible, for instance, for an adult with no prior music training
22 to develop absolute pitch. Our work asked a notably different question: whether the same sort
23 of rapid learning and automatization observed in (non-musical) incidental learning procedures
24 can also be observed in a pitch learning context. That is, with a drastically shorter learning
25 procedure, can evidence of improvements already be observed in explicit identification (i.e., in

1 our test phases)? And similarly, do we see automatic biases on performance during learning?
2 The answer to both of these questions seems to be “yes”. Posttest scores (accuracy and RTs), in
3 addition to RTs and error rate indices during learning, are impacted by the acquired
4 contingencies. In other words, participants not only improve their explicit tone naming scores,
5 but this retrieval is fast and automatic. Overall, the results suggest that an incidental learning
6 procedure can benefit the internalization of pitches and one reason why an incidental learning
7 procedure like ours works may be because of the many repetitions that participants can
8 experience in a small amount of time.

9 The present research may raise one interesting question. Why does our procedure work
10 at all? Specifically, if it is possible to incidentally learn pitch-label associations rapidly, then
11 why do all musicians not already have absolute pitch? Indeed, musicians spend many years
12 playing and listening to notes and they know the names of said notes. One significant difference
13 lies in the utilization of incidental learning, which typically is not emphasized in traditional
14 musical training such as solfege exercises that usually involve deliberate, instructed training.
15 Indeed, traditional musical instruction typically does not focus on specifically learning the
16 associations between pitches and note names. For example, most musical practice involves
17 learning procedural actions on the instrument from music notation, without the (necessary)
18 intermediary of note names. Subsequent repetition involves repetition from procedural memory
19 rather than specific practice of associating a pitch to a note name. Further, as suggested by an
20 anonymous reviewer, this sort of music practice could also provoke overshadowing as the focus
21 is *not* exclusively on the association between the note name and the pitch (e.g., also on the
22 musical notation, which produced overshadowing in our Experiment 1). Even aural exercises
23 that are typical in traditional instruction (e.g., interval training) tend not to focus on *absolute*
24 pitch detection. In general, traditional instruction (typically) does not seem to involve the type
25 of learning that is highly analogous to the current task. The fact that learning is incidental is

1 perhaps at least partially relevant, too. A key feature of more implicit types of learning is the
2 rapidity of this learning. It also seems particularly effective in cases where a regularity is very
3 difficult to learn in a conscious and deliberate manner. In some cases, intentional learning can
4 actually *hurt* performance (Berry & Broadbent, 1988; Reber, 1976; Reber et al., 1980; Wulf et
5 al., 1998). On the other hand, the results of our Experiment 3 do not suggest that deliberate
6 learning hurts in the present task.

7 What remains to be explored, however, is whether this type of approach could be
8 effective (e.g., with much longer training regimes, similar to past research) to acquire absolute
9 pitch, and whether our approach is more effective than other alternatives. Indeed, the present
10 work might pose an interesting question: Could our procedure (or something similar) be used
11 to train an adult AP non-possessor to acquire AP, strictly defined, or something approaching
12 this? The present experiments, while they do demonstrate impressively rapid improvements, do
13 not speak directly to this question. Here, we consider why they do not and what future research
14 might be conducted to empirically evaluate this question. First, we note that we presented
15 participants with a relatively small number of notes, the seven notes of a C Major scale. We did
16 not attempt to train participants with all 12 semitones of an octave (i.e., the smallest distance
17 between notes in the Western scale). This is, of course, quite different than prior work
18 investigating AP acquisition (Van Hedger et al., 2019; Wong, Lui, et al., 2020; Wong, Ngan, et
19 al., 2020). The reason for this methodological choice was that, contrarily to the previous studies,
20 we recruited nonmusicians and focused on short- and medium-term improvements in pitch
21 identification. Additionally, to parallel the structure of a more typical incidental learning task,
22 seven response choices is already quite a lot. Further, for a key press task, 12 responses would
23 be further complicated by the fact that participants do not, obviously, have 12 fingers.
24 Incidentally, in ongoing work with another graduate student of the last author using a
25 conceptually similar procedure, we have observed similar improvements in explicit pitch

1 naming with the 12 notes of an octave with a similarly short training procedure, though
2 automatic performance during learning (e.g., response times) was not assessed in this ongoing
3 research.

4 As another limitation, we did not implement standardized AP tests (see Van Hedger et
5 al., 2019, for some examples of AP tests) in our work. Standardized tests, though varying in
6 nature from one test to another, typically involve all 12 semitones of two or more octaves, often
7 in multiple timbres (i.e., played by different instruments). These tests also frequently include
8 large jumps of more than an octave between adjacent notes and potentially distracting white
9 noise between notes to prevent RP-type strategies. It is therefore possible that participants in
10 our experiments may not have learned pitch classes (e.g., the ability to identify a C in any octave
11 or timbre), but rather the pitch names of particular auditory stimuli. It is similarly possible that
12 participants used some form of an RP-comparison strategy. We did not use this type of
13 standardized test in the present research for a few reasons. First, as already mentioned, it was
14 not our aim to claim that our procedure can teach AP to nonmusicians. Rather, it was the goal
15 to determine whether there is something fundamentally unlearnable about pitch-label
16 associations. Second, we aimed to study short- to medium-term learning in naïve participants.
17 Octave- and timbre-generalization in more stringent tests of AP, we imagine, would require
18 longer training periods. In some recent and ongoing follow-up work, however, we have already
19 observed transfer of learning from trained timbres to untrained timbres (Henry & Schmidt,
20 2023) and some initial positive results in octave generalization. However, future research with
21 such standardized tests (and most likely: longer training) might aim to evaluate whether an
22 approach like the current one is capable of producing true AP and how this might compare to
23 other approaches.

24 In conclusion, in this series of studies we explored whether a musical contingency
25 learning procedure could aid in the rapid acquisition and consolidation of pitch-label

1 associations in memory. Although, our results suggest that incidental learning may have a
2 positive role in the acquisition of pitch-label associations as well as on its consolidation, more
3 research is needed in order to further determine the role of this kind of incidental acquisition in
4 the auditory domain.

5

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2 Acknowledgements

3 This work was supported by the French “Investissements d’Avenir” program, project
4 ISITEBFC (contract ANR15-IDEX-0003) to James R. Schmidt.

5

6 Originality statement

7 The authors declare that the manuscript entitled “*Incidentally acquiring pitch-label*
8 *associations with a musical contingency learning task*”, submitted for consideration for
9 publication to *Collabra: Psychology* is an original work. The authors confirm that the
10 article has not been published, nor is in the process of peer-reviewing, nor has been
11 accepted for publishing in another journal.

12 Supplementary material

13 Supplemental materials are available following the OSF link included in the manuscript.
14 All the supplemental material will be openly available after publication.