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# Intoxication and pitch control in tonal and non-tonal language speakers

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**Abstract:** Alcohol intoxication is known to affect pitch variability in non-tonal languages. In this study, intoxication's effects on pitch were examined in tonal and non-tonal language speakers, in both their native language (L1; German, Korean, Mandarin) and nonnative language (L2; English). Intoxication significantly increased pitch variability in the German group (in L1 and L2), but not in the Korean or Mandarin groups (in L1 or L2), although there were individual differences. These results support the view that pitch control is related to the functional load of pitch and is an aspect of speech production that can be advantageously transferred across languages, overriding the expected effects of alcohol. © 2022 Author(s). All article content, except where otherwise noted, is licensed under a Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

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## 1. Introduction

Consumption of alcohol, a central nervous system depressant, has long been known to affect speech production, including aspects of vocal pitch.<sup>1–3</sup> For example, research on English speakers in a repetition task found that intoxication up to a blood alcohol concentration (BAC) of at least 0.10%, while having little effect on overall mean fundamental frequency ( $f_0$ ) level for most speakers, consistently led to higher  $f_0$  variability than in sober (i.e., un intoxicated) speech, an effect “suggesting less precise control of the rate of vocal cord vibration” under intoxication.<sup>4</sup> Although it is not clear whether changes in  $f_0$  variability can be used to reliably identify intoxication, the finding of increased  $f_0$  variability in intoxicated speech has been replicated in other studies of English, which have also evinced individual differences in the presence and/or directionality of an intoxication effect on the mean  $f_0$  level.<sup>5,6</sup>

Previous studies of other languages have contributed to a fuller picture of how speakers' pitch control may be affected by intoxication, suggesting that there may be considerable crosslinguistic variability in this regard. On the one hand, German speakers have mostly shown an increase in mean  $f_0$  and  $f_0$  range under intoxication, but also a number of individual differences.<sup>7</sup> On the other hand, Japanese speakers have shown a significant decrease in mean  $f_0$  as well as a non-significant tendency toward an expanded  $f_0$  range.<sup>8</sup> One potential contributor to such crosslinguistic variability is typological variation among languages in the functional role played by a given cue. In the case of  $f_0$ , this may serve primarily to signal pragmatic distinctions at the sentence/utterance level (*intonation* languages, e.g., English), lexical contrasts in part of the vocabulary (*pitch-accent* languages, e.g., Japanese), or lexical contrasts across the entire vocabulary (*tonal* languages, e.g., Mandarin Chinese). The fact remains, however, that there are very few acoustic studies of intoxicated speech in languages that are not English, thus, limiting any typological account of crosslinguistic variability.

Apart from typological differences in the role of  $f_0$ , another potential contributor to variation in the effects of intoxication is experience (and proficiency) in the target language. In particular, it has been suggested that effects of intoxication differ for one's native language (L1; generally an early-learned and relatively strong language) and a nonnative language (L2; generally a later-learned and relatively weaker language). For instance, whereas intoxication has generally been found to negatively affect production in a speaker's L1, it was found to positively affect production in an unfamiliar L2

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(as measured by global accent ratings), which was attributed to intoxication modifying a speaker's "language ego" in a manner facilitating authentic (i.e., native-like) L2 pronunciation.<sup>9</sup> Along the same lines, Dutch speakers have shown a detrimental effect of alcohol consumption on the clarity of their L1 (Dutch) speech but no such effect on the perceived nativelikeness of their L2 (English) speech.<sup>10</sup>

Notably, the L1-L2 disparities in intoxication effects at a global level stand in contrast to the findings of acoustic studies of bilingual speech, which often provide evidence of similarities—and, by implication, interconnections—between the L1 and L2, including in aspects of prosody.<sup>11–14</sup> Findings showing crosslinguistic influence related to pitch control have been reported for  $f_0$  alignment in L1 Dutch–L2 Greek and L1 German–L2 English speakers,<sup>15,16</sup>  $f_0$  range for L1 Welsh–L2 English speakers (albeit mostly for males),<sup>17</sup> and  $f_0$  level for L1 English–L2 Korean speakers,<sup>18–20</sup> consistent with the view that there is a crosslinguistically "shared control mechanism for  $f_0$  modulation."<sup>18</sup> Few studies, however, have examined  $f_0$  variability crosslinguistically, much less in conditions that undermine articulatory control, such as intoxication.

Thus, in the current study, we bring together typological and acquisition-related concerns to ask two questions regarding the effects of alcohol intoxication on speech production. First, does intoxication affect pitch variability similarly across languages that differ in the level of pitch control they require, such as tonal and non-tonal languages (Q1)? Second, do sequential bilinguals of diverse L1–L2 backgrounds show similar effects of intoxication on pitch variability in their L1 and L2 (Q2)? To investigate these questions, we carried out a bilingual acoustic study of intoxicated speech produced by L2 English speakers from three L1 backgrounds: German (an intonation language), Korean (an intonation language with tone-like contrasts in certain phrase-prosodic positions),<sup>21,22</sup> and Mandarin (a tonal language). Under the assumption that speakers' articulatory control of a phonetic cue reflects the cue's relative functional load in the language (i.e., the unique linguistic burden it bears in signaling contrasts),<sup>23</sup> L1 Mandarin speakers will be predisposed toward greater pitch control than L1 German or L1 Korean speakers, because the relative functional load of pitch is the highest in Mandarin.<sup>24</sup> This leads to the hypothesis that intoxication will impact the variability of  $f_0$  (the acoustic correlate of pitch) less for L1 Mandarin speakers than for L1 German or Korean speakers (H1). Furthermore, if  $f_0$  is indeed modulated at least in part by a control mechanism that is shared between languages, this leads to the hypothesis that, for all L1 groups, effects of intoxication on  $f_0$  variability will look similar in the L1 and L2 (H2).

## 2. Methods

### 2.1 Participants

To be included in the study, participants had to: (a) identify as a native speaker of one of the target L1s, (b) identify as an L2 speaker of English, (c) be at least 21 years old, (d) not have been diagnosed with hearing deficits or speaking disorders, (e) not be currently pregnant, and (f) not be struggling with alcohol-related problems of any kind (e.g., alcoholism). The three L1 groups comprised native speakers of German [ $N=8$ ; 4 female, 4 male; mean age ( $M_{age}$ ) = 27.1 years, standard deviation (SD) = 4.3], Korean ( $N=8$ ; 8 female, 0 male;  $M_{age}$  = 27.1 years, SD = 3.8), and Mandarin ( $N=17$ ; 10 female, 7 male;  $M_{age}$  = 23.8 years, SD = 1.5) who were born and raised/educated in an L1-dominant environment (i.e., Germany, South Korea, mainland China, respectively) and self-reported their L2 English level as fluent. In the Korean group, most participants (7) were from Seoul or the surrounding Gyeonggi province, with one from the North Gyeongsang province; thus, most spoke Seoul Korean or a similar dialect. In all groups, most participants were students who had been living in the United Kingdom for 1–2 years at the time of the study.

Two types of objective data on participants' L2 English proficiency were collected. First, International English Language Testing System (IELTS) scores were collected if available. IELTS scores were high overall and did not differ significantly between groups (Welch-corrected two-sample  $|t|s < 1.7$ ,  $ps > 0.05$ ). The group means were all in the 7.0 band of the IELTS scale, which indicates being a "good" user of the English language and translates to a "lower advanced" (C1) level of proficiency in the Common European Framework of Reference (CEFR).<sup>25</sup>

Second, vocabulary-based LexTALE<sup>26</sup> scores were collected from the Korean and Mandarin groups only. LexTALE scores were high (in the 60s) and did not differ significantly between groups (Welch-corrected two-sample  $|t| = 0.410$ ,  $p = 0.680$ ). The group means were consistent with "upper intermediate" (B2) proficiency in the CEFR. Thus, both proficiency metrics suggested that participants were relatively proficient users of English.

### 2.2 Materials

The speech materials for each language were based on dialogues in a play or drama: *Goncourt oder Die Abschaffung des Todes* for German,<sup>27</sup> *Coffee Prince* for Korean,<sup>28</sup> *Two Dogs' Opinions on Life* for Mandarin,<sup>29</sup> and *The Good Doctor ("The Governess," scene 3)* for English.<sup>30</sup> The original text of each dialogue was edited to ensure that it was gender-neutral, emotionally neutral (e.g., by removing jokes), contemporary (e.g., by removing archaic words), without overly long turns, and representative of the phonemic inventory of the language.<sup>31</sup>

### 2.3 Procedure

The speaking task was completed in a sound-insulated room in London. Participants were instructed to read the two target dialogues naturally (i.e., not to put on an acting voice) and were seated in front of a microphone while facing the experimenter; the two went through each target dialogue together, with the participant reading one character's lines and the experimenter reading the other's lines. Recordings were made at 44.1 kHz with 16-bit resolution in stereo and were then converted to mono using Audacity.

Participants read the target dialogues in two drinking conditions (*sober* and *intoxicated*) in separate sessions on different days, no more than 14 days apart. They were instructed not to eat, drink, or use mouthwash in the 2 h before each session and not to smoke in the half hour before each session. With the exception of the Korean speakers (who completed the conditions in the same order: sober and then intoxicated), the order in which the drinking conditions were completed was counterbalanced across participants. The LexTALE proficiency test was completed at the end of the sober condition.

In both conditions, participants' BAC was tested and monitored using a breathalyzer [AlcoMate (Macomb Township, MI) Premium AL-7000]. BAC was measured at the start of the session to ensure that participants came in with no alcohol in their system. In the intoxicated condition, participants consumed a predetermined amount of alcohol (vodka or rum, mixed with orange, lemon, or apple juice), estimated on the basis of their self-reported weight and BAC charts,<sup>32</sup> to reach a target BAC of 0.12%. Three-quarters of the alcohol was first poured into a glass; participants then decided on the amount of mixer and drank the mixture at their own pace. BAC was tested 15 min after the mixture was consumed and then every 3–5 min until it went over 0.12% and dropped back down to 0.12%. If BAC never got up to 0.12% at this point, a small top-up was given from the remaining alcohol. Once BAC had hit 0.12%, participants were taken into the recording room to complete the speaking task.

### 2.4 Analysis

For the purposes of analysis, each audio recording was divided into a set of utterances. An utterance was defined as a breath group, a stretch of speech often flanked by silent pauses and/or audible inhalations and often (but not always) coinciding with a sentence or clause. Given that speakers may exhibit a higher rate of disfluencies and speech errors when intoxicated,<sup>33,34</sup> the utterances were aurally inspected for disfluencies, speaker-generated noise, background noise, errors, and inaudibility. Utterances that contained one or more of the above issues were excluded from further analysis (such exclusions comprised 8%–13% of all utterances across the three participant groups). If an utterance was produced multiple times consecutively (restarts), the last production was kept if it was free of errors.

Following aural inspection, utterances were subjected to acoustic analyses of  $f_0$  and duration in Praat.<sup>35</sup> The  $f_0$  analysis used the Praat function "To Pitch (cc...)" (cross correlation), with a pitch floor and ceiling of 50 and 300 Hz, respectively, and a time step of 0.01 s. From Praat's voice report for a given utterance, a SD of  $f_0$  was extracted, yielding the dependent variable of  $f_0$  variability, as well as a total duration value for the utterance. The final dataset submitted to statistical analysis comprised 17 083 data points (utterances/items): 3742, 4551, and 8790, respectively, in the German, Korean, and Mandarin groups.<sup>36</sup>

The  $f_0$  variability data were analyzed in four linear mixed-effects models using `lmerTest`<sup>37</sup> in R,<sup>38</sup> with sum coding of all categorical fixed effects.<sup>39</sup> Model 1, built on the L1 data, tested H1 and contained fixed effects for group, condition, and their interaction. Models 2–4, one model per L1 group, tested H2; each contained fixed effects for language, condition, and their interaction. Up to two control variables were also added to these models: duration (ms; log-transformed to the base of 10 and then z-transformed), which was added to all models, and gender, which was added to all models except for the Korean group model (since all Korean participants were female). Duration was included to account for the possible dependence between  $f_0$  variability and utterance duration.<sup>40</sup> Where relevant, gender was also included as it is known to influence  $f_0$  variability.<sup>41</sup> All models contained the maximal random-effects structure by participant and item.

All models underwent the process of model criticism.<sup>42</sup> For each model, the residuals were extracted, and data points that were more than 2.5 SD above or below the mean residual value were excluded. This process resulted in no more than 2.1% of the data points being excluded from any of the models. Fixed-effect summaries of the final models can be found in the Appendix, which shows model formulas in the table captions. Post hoc comparisons were carried out using `emmeans` (without p-value adjustment).<sup>43</sup>

## 3. Results

### 3.1 Question 1: Intoxication effects by L1 background

Median  $f_0$  variability was higher in the intoxicated than the sober condition for all groups (Fig. 1). The intoxication effect differed across items, but a majority (62% for German, 57% for Korean, 56% for Mandarin) showed higher variability in the intoxicated condition.

Results of model 1 partially supported H1: the effect of intoxication was indeed smaller (in fact, not significant) in Mandarin, but this was also the case in Korean. Model 1 indicated a significant condition effect overall, with intoxicated

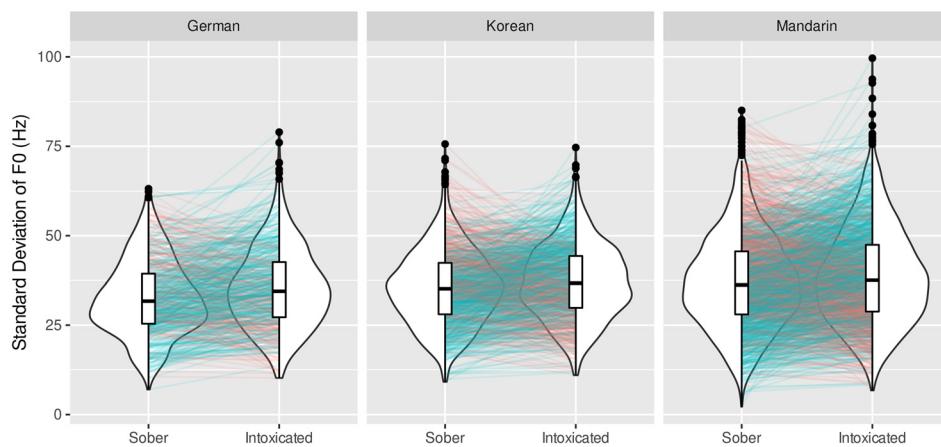


Fig. 1. Variability (SD) of  $f_0$  in Hz in L1 utterances (items), by L1 group, condition, and item (horizontal lines). Blue indicates higher variability for the given item in the intoxicated condition.

speech showing higher-than-average variability ( $\beta = 2.064, t = 3.514, p < 0.001$ ).<sup>44</sup> However, because interaction coefficients were negative, suggesting a reduced effect in Korean and Mandarin, we further inspected the magnitude of the intoxication effect (i.e., intoxicated – sober) by group/L1, finding a significant effect in German (estimate = 3.232,  $z = 2.847, p = 0.004$ ) but not in Korean (estimate = 1.690,  $z = 1.555, p = 0.120$ ) or Mandarin (estimate = 1.269,  $z = 1.671, p = 0.095$ ). As always, null results should be interpreted cautiously; crucially, however, the null result (i.e., no intoxication effect) for Mandarin is consistent with H1. As for control predictors, there was a positive duration effect ( $\beta = 0.907, t = 2.796, p = 0.007$ ) and also a gender effect, whereby males showed lower-than-average variability ( $\beta = -7.404, t = -3.909, p < 0.001$ ).

### 3.2 Question 2: Intoxication effects within the linguistic repertoire

Median  $f_0$  variability was higher in the intoxicated than the sober condition across all groups and languages (Fig. 2), but intoxication effects were largest in the German group. Results of models 2–4 fully supported H2: for all groups, intoxication effects were similar between the L1 and L2. Inspection of intoxication effects by group and language revealed the same pattern in a group's L2 English as was observed in their L1: the German group showed a significant effect (estimate = 2.960,  $z = 2.670, p = 0.008$ ), while the Korean (estimate = 1.327,  $z = 0.716, p = 0.474$ ) and Mandarin (estimate = 1.900,  $z = 1.708, p = 0.088$ ) groups did not. As for control predictors, there was no significant duration effect in any model ( $|\beta|'s < 0.6, |t|'s < 1.6, p's > 0.05$ ) and a significant gender effect only in model 4, whereby males showed lower-than-average variability as above ( $\beta = -9.084, t = -4.078, p < 0.001$ ).

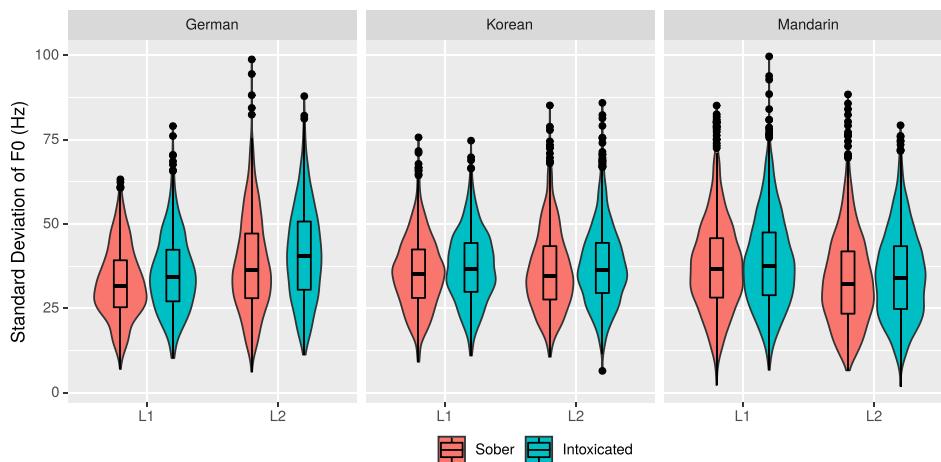


Fig. 2. Variability (SD) of  $f_0$  in Hz, by L1 group, language (L1 or L2), and condition.

#### 4. Discussion

This study directly compared the effects of intoxication on pitch control in speakers of tonal and non-tonal languages. It found evidence for a shared control mechanism for  $f_0$  employed by bilinguals in their two languages: by allowing no significant increase in  $f_0$  variability under intoxication, L1 speakers of Mandarin, a tonal language, showed greater overall control of  $f_0$  variability in both the L1 and L2 (English), despite the fact that English is not a tonal language. Unexpectedly, greater overall pitch control was also found for L1 speakers of Korean, a non-tonal language; this may be related to a “quasi-tonal” prosodic system, in which there are no lexically specified tones but  $f_0$  plays an important role in a limited set of phrasal positions as a cue to different consonantal laryngeal categories, which may in turn distinguish different lexical items. On the other hand, L1 speakers of German, a non-tonal language whose  $f_0$  use is similar to that of English, showed less overall pitch control under intoxication in both the L1 and L2 data.

These findings have implications for phonetic typology as well as theories of bilingual phonology. First, while the results are compatible with the assertion that (Seoul) Korean is a “quasi-tonal” language, different types of languages verge on tonal (e.g., pitch-accent languages), and specific dialects may fall along a continuum of  $f_0$  use, as has been shown for other languages (e.g., Basque, Japanese, Swedish).<sup>45,46</sup> In the case of Korean, there has been discussion about the status of some dialects as pitch-accent varieties, which points to the potential utility of intoxicated speech as a source of data on pitch control in speakers of understudied varieties. As above, null effects in this paradigm need to be interpreted cautiously, as they may arise for a number of reasons (e.g., individual differences in the effect of intoxication, socio-cultural factors related to appearing intoxicated); nevertheless, where intoxication consistently fails to affect speech production may turn out to be just as informative as where it does. Second, the current results support the view that bilingual phonological representations for pitch tend to be shared to some degree,<sup>15–20</sup> but more research is needed to understand the generalizability of these results to (psycho-)typologically different L1-L2 pairings. For instance, the consistent use of a non-tonal language as the L2 in the present study invites the question of what would happen when a tonal language is the L2. For example, might L1 English-L2 Mandarin speakers show, unlike L1 Mandarin-L2 English speakers, *less* overall pitch control under intoxication?

In closing, we would like to acknowledge two limitations of the current study, which point toward directions for future research. First, our findings are limited to read speech, which is known to show smaller effects of intoxication on  $f_0$  properties than other speaking styles.<sup>7</sup> Therefore, it would be worthwhile to extend this work to diverse L1 populations producing a variety of speaking styles, including spontaneous speech. Second, this study leaves us with an incomplete picture of the role of gender, as our dataset did not allow an examination of gender effects in all groups. Given previous evidence of gender differences in  $f_0$  modulation across languages,<sup>17</sup> it would, thus, be useful to further examine the effects of gender on  $f_0$  variability. In addition, future research could explore correlations of  $f_0$  variability changes with individual-difference variables (e.g., working memory), examine the effect of specific intonational tunes in our target dialogues on  $f_0$  variability, and compare the effects of intoxication with other conditions known to affect speech, such as sleep deprivation.

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#### APPENDIX

See Tables 1–4 for fixed-effect summaries of the final models.

Table 1. Fixed effects in model 1 (L1 data only). Model formula: F0Var ~ duration + gender + group + condition + group:condition + (1 + duration + gender + condition|item) + (1 + duration + condition|participant). Significance codes: \*,  $p < 0.05$ ; \*\*,  $p < 0.01$ ; \*\*\*,  $p < 0.001$ .

	$\beta$	SE <sup>a</sup>	<i>t</i>	<i>p</i>
(Intercept)	33.751	1.054	32.026	<0.001***
Duration	0.907	0.324	2.796	0.007**
Gender: male (vs grand mean)	-7.404	1.894	-3.909	<0.001***
Group: Korean (vs grand mean)	-3.133	2.759	-1.136	0.264
Group: Mandarin (vs grand mean)	5.255	2.368	2.219	0.033*
Condition: intoxicated (vs grand mean)	2.064	0.587	3.514	<0.001***
Group: Korean × condition: intoxicated	-0.748	1.703	-0.439	0.664
Group: Mandarin × condition: intoxicated	-1.589	1.446	-1.099	0.280
Observations: 7822; participants: 33; items: 394				

<sup>a</sup>Standard error (SE).

Table 2. Fixed effects in model 2 (German group). Model formula: F0Var ~ duration + gender + language + condition + language:condition + (1 + duration + gender + condition|item) + (1 + duration + language + condition + language:condition|participant). Significance codes: \*,  $p < 0.05$ ; \*\*,  $p < 0.01$ ; \*\*\*,  $p < 0.001$ .

	$\beta$	SE	$t$	$p$
(Intercept)	35.174	2.740	12.836	<0.001***
Duration	-0.577	0.550	-1.049	0.321
Gender: male (vs grand mean)	-4.611	2.581	-1.786	0.115
Language: L2 (vs grand mean)	5.465	1.664	3.284	0.012*
Condition: intoxicated (vs grand mean)	2.885	0.616	4.684	0.002**
Language: L2 × condition: intoxicated	0.154	1.288	0.120	0.908
Observations: 3661; participants: 8; items: 255				

Table 3. Fixed effects in model 3 (Korean group). Model formula: F0Var ~ duration + language + condition + language:condition + (1 + duration + condition|item) + (1 + duration + language + condition + language:condition|participant). Significance code: \*\*\*,  $p < 0.001$ .

	$\beta$	SE	$t$	$p$
(Intercept)	36.227	1.045	34.666	<0.001***
Duration	0.582	0.408	1.425	0.176
Language: L2 (vs grand mean)	0.193	1.577	0.122	0.906
Condition: intoxicated (vs grand mean)	1.561	1.105	1.413	0.200
Language: L2 × condition: intoxicated	-0.467	1.796	-0.261	0.802
Observations: 4476; participants: 8; items: 318.				

Table 4. Fixed effects in model 4 (Mandarin group). Model formula: F0Var ~ duration + gender + language + condition + language:condition + (1 + duration + gender + condition|item) + (1 + duration + language + condition + language:condition|participant). Significance code: \*\*\*,  $p < 0.001$ .

	$\beta$	SE	$t$	$p$
(Intercept)	34.757	1.203	28.903	<0.001***
Duration	0.516	0.324	1.594	0.121
Gender: male (vs grand mean)	-9.084	2.228	-4.078	<0.001***
Language: L2 (vs grand mean)	-5.121	1.031	-4.967	<0.001***
Condition: intoxicated (vs grand mean)	1.649	0.981	1.681	0.112
Language: L2 × condition: intoxicated	0.509	0.758	0.671	0.512
Observations: 8612; participants: 17; items: 295				

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