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# Improved Source Characteristics of a Handclap for Acoustic Measurements: Utilization of a Leather Glove

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**Abstract:** A handclap is a convenient and easily available source for room acoustic measurements. If used correctly (e.g., application of optimal hand configuration) it can provide usable results for the measurement of acoustic parameters, within an expected deviation. Its biggest drawbacks are the low sound pressure level (especially in the low frequency range) as well as its low repeatability. With this in mind, this paper explores the idea of testing a handclap with a glove in order to assess the effect on its source characteristics. For this purpose, measurements were performed with 12 participants wearing leather gloves. Sound levels were compared with simple handclaps without gloves, and between grouped results (overall A-weighted SPL, octave bands, 1/3 octave bands). Measurements were also performed several times to evaluate the effect on repeatability. Results indicate that the use of leather gloves can increase the sound levels of a handclap by 10 dB and 15 dB in the low frequency ranges (63 Hz and 125 Hz octave bands, respectively). Handclaps with leather gloves also point toward improved repeatability, particularly in the low-frequency part of the frequency spectrum. In conclusion, compared to simple handclaps without gloves, evidence from this study supports the concept that handclaps with leather gloves can be used in engineering practices for improved room acoustic measurements of room impulse response.

**Keywords:** room acoustic measurement; ISO 3382; survey method; excitation signal; ordinary rooms; sound source; acoustic parameters; impulse response

## 1. Introduction

A sound source with omnidirectional characteristics is required in many room acoustic measurements, and the most common practical implementation is that of a dodecahedron speaker. Commercially available dodecahedron speakers are manufactured in order to meet ISO 3382-1 [1] source requirements of omnidirectionality (a maximum deviation of directivity is allowed) and of the creation of sufficient sound pressure levels (without contamination by background noise). Drawbacks of dodecahedron speakers are their high cost, heavy weight, and also the need for an electricity supply, while alternative sources for room acoustic measurements [2] exist, such as balloons [3], gunshots [4], firecrackers [5], inverse horn designs [6], wooden clappers [7], rotation of a directional speakers [8], ultrasound piezoelectric transducers [9], and ring radiators [10].

A handclap is also an alternative source for room acoustic measurements which is useful, convenient, and easily available. It is used by the industrial and academic communities for the measurement of the acoustic characteristics of indoor spaces [11]. A study on the sound generation of a handclap [12] has shown that a shock wave can be created with the addition of a Helmholtz-type resonance in the case of domed impacts. Eleven different clapping modes according to hand configuration have been identified [13], while additional variations may derive from such factors as hand curvature, stiffness, fleshiness of the palms, tightness of the fingers, precision, and striking force [14].

Regarding the source characteristics of a handclap, results for omnidirectionality, repeatability, sound pressure levels, and frequency response, as well as its efficiency as a source for room acoustic measurements can be found in various studies. Concerning omnidirectionality, a study revealed that it has directional characteristics with differences of more than 15 dB in certain frequency ranges [15]. On the subject of repeatability, the handclap may have one of the lowest performance among acoustic sources, the reason being that variations of hand configuration may alter the generated impulse and spectral characteristics, and also there is considerable variability in the spectral shapes of handclaps across individuals [14]. On the subject of frequency response, studies [13,14] measured different hand configurations and found in general that a roll-off is evident below 500 Hz for all of them. However, domed hand configurations have a subsidiary maximum that is caused by Helmholtz resonance, which results in an increased level in the low frequency range.

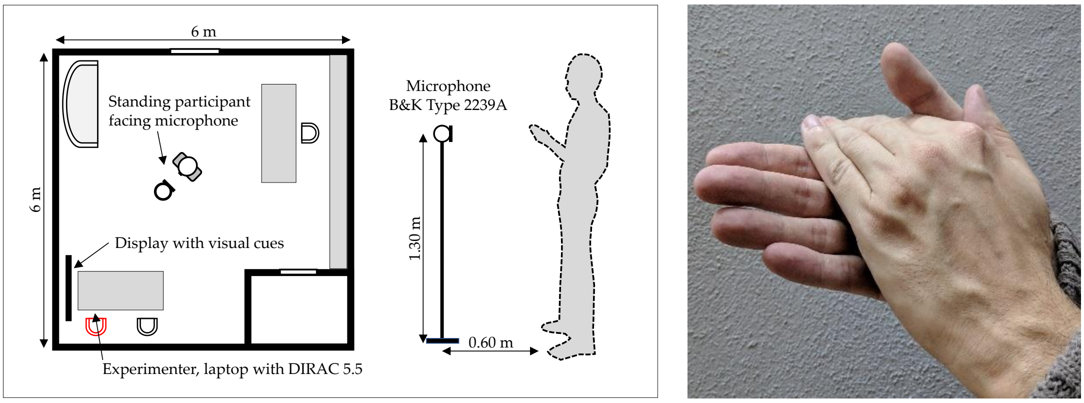
Regarding measurements of acoustic parameters, all the studies found in the literature where the handclap was used as an acoustic source [13,16–19] showed that results for the low frequency range were unreliable. However in [13], reverberation time was measured across different spaces and positions, with a deviation of less than 3 JND (just-noticeable difference) for signal to noise ratio, and within or near the ISO 3382-1 limits for each corresponding octave band. In the same study, other acoustic parameters (early decay time, clarity) were measured with greater deviations. In other words, handclaps are often unsatisfactory for performance spaces. However for ordinary rooms, for which the requirements of measurement conditions are stated in ISO 3382-2 [20], handclap measurements are likely to be an adequate alternative to other sound sources because of simplicity of use [2] and less stringent requirements.

The aim of this study is to explore the idea of using leather gloves in order to improve the source characteristics of a handclap. To the best of our knowledge, this is the first study that explores the use of gloves for room acoustic measurements, and also the first that through evidence highlights the improvements of the sound pressure levels of a handclap in the low frequency range, as well as its repeatability.

This paper is organized as follows: Section 2 analyses the methodology employed for this study, while in Section 3 the findings of the research are presented. Section 4 analyses the data gathered and in turn addresses the research questions.

## 2. Materials and Methods

Figure 1 provides a schematic illustration of the measurement setup (Figure 1a) and a photo of the optimal hand configuration for room acoustic measurements (Figure 1b). Handclaps with the use of four different leather gloves were investigated and compared with simple handclaps (i.e., without wearing gloves). In all cases, handclaps were produced following the optimized A1+ hand configuration presented in [13,14]. The leather gloves were of the same brand and model (Men's classic with velvet lining, Duskgoo, Honk Kong S.A.R.) and only varied in their size: M, L, XL, and XXL. Each of the participants wore one pair of leather gloves that best fitted corresponding to their hand size, and the largest available pair. This is because the availability of well-fitting gloves might not always be obvious in practice. An oversized model might serve smaller hands, whereas a small size won't serve larger hands. Therefore, as a third configuration, every participant also wore the largest glove size (XXL). Participants received information about the goal of the measurements and the procedure upon invitation to the experiment, as well as in a brief 10-min instruction, with the opportunity to practice just before the measurement procedure.




(a) (b)

**Figure 1.** In the left panel (**a**) the schematic presentation of the measurement setup, and in the right panel (**b**) a photo of the optimized A1+ hand configuration for room acoustic measurements [13].

Twelve participants, age (M = 29.7, SD = 4.5), six females, volunteered for the measurements, at Beijing Tongheng Urban Planning and Design Institute (THUPDI) dept. Acoustic & Interior Design (Beijing, P.R. China). All participants gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Committee on Research Ethics and Conduct, Polytechnic Campus, Technical University of Crete (Project identification code 23/29.09.2020).

Under supervision of one experimenter, acoustic measurements of the handclaps were carried out using an omnidirectional microphone (Type 2239A, Brüel & Kjær, Denmark), sampled at 48 kHz 16-bit depth with an USB-audio device (Type ZE0948, Acoustics Engineering, The Netherlands), and a laptop computer with acoustics measurement software (DIRAC 5.5, Acoustics Engineering, The Netherlands). The input level was calibrated at 94 dB SPL using a calibrator (Type 4231, Brüel & Kjær, Denmark). "External impulse measurements" were performed according to the default durations of the DIRAC software [21]. The microphone was positioned at a 1.3-m height above the floor of a furbished office space, at 0.6-m from the standing participant. The distance between the sound source and the microphone was shorter than the estimated critical distance of the measurement room (volume 97 $m^3$, reverberation time approximately 0.5 s).

Prior to the handclap measurements, for each participant, the background noise was measured for a duration of 43.7 s with the participant standing still in front of the microphone. Measurements of handclaps were conducted and stored automatically using the built-in auto-measure function of the DIRAC software. For each handclap configuration, 25 handclaps were obtained. Each measurement duration was set at 1.37 s. Throughout the measurement procedure, full-screen visual cues were displayed on a computer display. Immediately after the presentation of every visual cue, the participant produced a single handclap, and awaited the subsequent visual cue. Participants were instructed to strike their hands at maximal (yet comfortable) force, respecting the A1+ hand configuration as well as possible (Figure 1b), and to retain their hands in closed position after each handclap, only to get separated briefly (when striking) upon the next visual cue. As soon as all measurements were completed, this was visually clarified by an "OK" message prompting on the display. For all participants the entire experimental procedure consisting of a brief instruction, practice of handclaps, and all measurements with short breaks in between, was completed within 25 to 30 min.

The initial five measurements per configuration are excluded from the results of this paper. Their purpose was familiarization with the measurement routine, establishing optimal concentration on the task, and handclap consistency. The remaining 20 handclaps were analyzed for equivalent sound pressure level (SPL) for a time window of 125 ms after the first arriving sound to reduce the influence of reverberation. In this paper we present the results for 1/3-octave bands from 50 Hz to 12,500 Hz, full-octave bands from 63 Hz to 8000 Hz, and the total A-weighted SPL.

## 3. Results

In this section we present the results of handclap measurements for different groupings of the participants. Information about the participants is given in Table 1. None of the male participants had the medium glove size as preference, whereas none of the female participants preferred the extra-large (XL). The double-extra-large (XXL) glove was never selected as an appropriate fitting glove.

**Table 1.** Information about participants (gender, and preferred glove size).

| Participant | Gender | Preferred Glove Size |
|---|---|---|
| 1 | male | L |
| 2 | female | L |
| 3 | female | M |
| 4 | male | XL |
| 5 | female | M |
| 6 | male | L |
| 7 | female | M |
| 8 | male | L |
| 9 | male | L |
| 10 | female | M * |
| 11 | female | M |
| 12 | male | XL |

* a smaller glove size was preferred if possible.

Table 2 displays more information about how the SPL results are further displayed. In addition to this, the total number of analyzed handclaps, the total A-weighted mean SPL, and the corresponding standard deviations per group are given in Table 2.

**Table 2.** Information about the grouping of results (N: total number of analyzed handclaps per group), and arithmetic A-weighted mean SPL per group (SD: standard deviation).

| Group | N | Mean SPL | SD |
|---|---|---|---|
| Males w/o | 120 | 89.5 | 4.2 |
| Females w/o | 120 | 87.9 | 4.6 |
| Males gloves | 120 | 93.0 | 3.7 |
| Females gloves | 120 | 89.9 | 3.3 |
| M | 100 | 89.9 | 3.5 |
| L | 100 | 92.4 | 3.6 |
| XL | 40 | 93.1 | 3.7 |
| XXL | 240 | 91.1 | 4.2 |

It can be observed that the total (A-weighted) sound level of the handclaps was always higher when participants were wearing the preferred leather glove size. We found that male subjects generally produced louder claps than females. The difference was 1.6 dBA without gloves, and 3.1 dBA with leather gloves, respectively. For both females and males, the standard deviation, which identifies variability within the grouped claps, decreased when participants wore leather gloves. The standard deviation on A-weighted SPL was reduced by 0.5 dBA for males, and by 1.3 dBA for females.

When the results are grouped per glove size, sound level differences per gender can still be observed (M-size are females, L-size contains only 1 female, XL-size are males). For the XXL glove (mixed gender), larger standard deviation was found compared to better fitting glove sizes. The mean

SPL was higher than the results for the "Females with gloves", but lower than the "Males with gloves" group.

In Figure 2, we present the spectral SPL results categorized by gender, for the handclap without wearing gloves, and for the preferred glove size (i.e., preferred glove sizes mixed within the grouped results). Figure 3 presents the spectral SPL results categorized by glove type (mixed gender). For all displayed results, the SPL of the background noise was more than 10 dB lower.

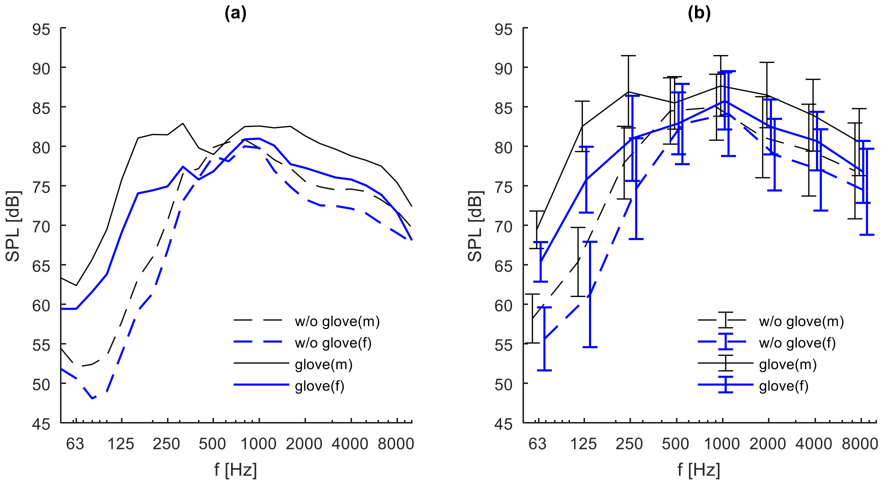



**Figure 2.** Sound pressure levels (re. 20 μPa) of handclaps for male (black, denoted "(m)") and female (blue, denoted "(f)") participants, with wearing gloves in the preferred size (solids), and without wearing gloves (dashed). Each line gives the arithmetic mean SPL for 120 handclaps. The left panel (**a**) gives 1/3-octave band SPL. The right panel (**b**) gives octave band SPL with standard deviations as error bars. Males used the L (n = 4) or XL (n = 2) glove sizes. Females used the M (n = 5) or L (n = 1) glove sizes. None of the participants had the XXL glove as preferred size, hence the results of this glove are not included in this figure. All handclaps were according to the A1+ hand configuration. The results in the right panel have a slight horizontal offset, for readability purposes.

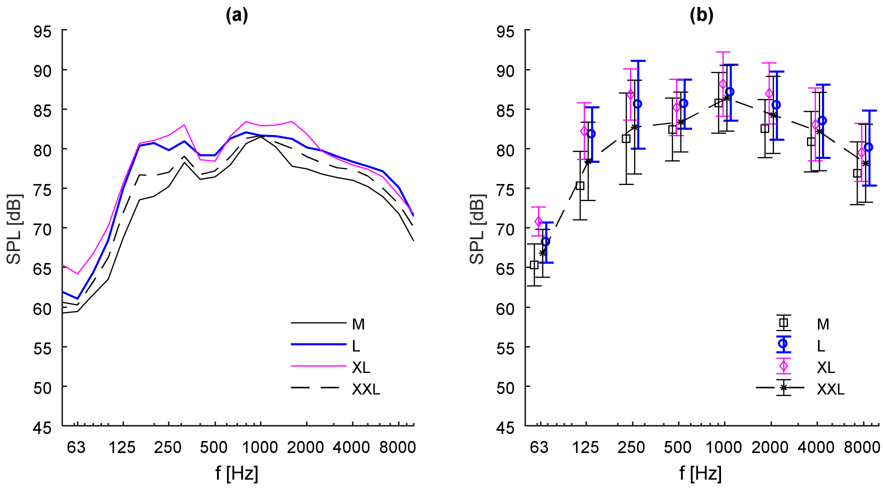



**Figure 3.** Sound pressure levels (re. 20 μPa) of handclaps, grouped for glove size: medium (M, black, N = 100), large (L, blue, N = 100), extra-large (XL, magenta, N = 40), and double-extra-large (XXL, dashed black, N = 240). Genders are mixed in the grouped results. The left panel (**a**) gives 1/3-octave band SPL. The right panel (**b**) gives octave band SPL, with standard deviations as error bars. All handclaps were according to the A1+ hand configuration. The results in the right panel have a slight horizontal offset, for readability purposes.

When comparing the spectrum of simple handclaps with the handclaps with leather gloves (Figure 2), substantial differences were found in the lower part of the audio spectrum (i.e., the entire range below 500 Hz). Just like simple handclaps, the acoustic energy in the lowest range of the audio spectrum demonstrated a roll-off toward the lower frequencies. However, in the 1/3-octave range of 63 Hz to 200 Hz, the leather glove handclaps were more than 10 dB louder, and even more than 15 dB louder in the 100 Hz to 160 Hz 1/3-octave range. Furthermore, in the higher audio range (1000 Hz to 8000 Hz) the leather glove handclaps contained more sound energy than the simple handclap. With respect to variability, standard deviations were smaller across the entire audio spectrum for the leather glove handclaps. The SD was the largest in the 250 Hz octave band, regardless of wearing gloves, but larger for females. In the 63 Hz to 125 Hz range, the standard deviations were much lower than for the higher frequency ranges. In addition, in the 63 Hz to 125 Hz range, the leather glove handclaps for both males and females showed reduced variability compared to simple handclaps. The variability at the 63 Hz octave band was reduced, with 0.7 dB for males, and 1.5 dB for females. For the 125 Hz octave band, the standard deviation for males was reduced by 1.2 dB, and 2.5 dB for females.

Considering the shape of the frequency spectrum per glove size, similarities between glove sizes were apparent (Figure 3). The XL-glove (only male participants) had the highest SPL across the full spectrum, whereas the M-glove (only female participants) showed the lowest SPL. The XXL-glove SPL (males and females combined) were in between these. The L-glove SPL resembled the XL-glove SPL, with somewhat lower SPL between 200 Hz to 2500 Hz. Standard deviations were the largest between 160 Hz to 315 Hz, with the largest deviation occurring for the M-glove. In the 50 Hz to 125 Hz range, the standard deviations were lower than for the remaining (higher) frequency range for all glove sizes. The XXL-size had larger variability of spectral SPL than other (better-fitting) glove sizes.

## 4. Discussion

In the results of this paper we have presented two beneficial effects of wearing gloves: a richer frequency content, and reduced variability.

Compared to simple handclaps, leather glove handclaps had higher (overall) SPL, which was characterized by substantially higher sound energy in the low frequency-range (63 Hz and 125 Hz octave band), as well as the higher frequency-range (above 1000 Hz). When measuring room impulse responses, the lower frequency bands are typically dominated by higher background noise levels. This makes measurements challenging when sound sources with limited energy in this frequency range are used; the obtained decay range generally becomes less sufficient at lower frequencies. Compared to simple handclaps, the leather glove handclaps have more potential for overcoming this challenge. Except for two participants, most participants had no experience with performing handclaps for room acoustic measurements. Nevertheless, all participants demonstrated improved source characteristics by wearing leather gloves. Future work could explore the sound source characteristics in greater detail (e.g., directivity and sound power level, different glove types) following standardized measurement conditions.

In our results, despite similarities in spectral shape, differences between the gender groups were found (Figure 2). Besides variation in male and female physique this could also be attributed to the (voluntary) striking force. Participants were encouraged to produce handclaps as loud as comfortably possible. The striking force was not studied in detail. Some participants notified the experimenter about a reduced tactile force perception when wearing leather gloves (i.e., gloves reduced the sensation of two hands striking together), which allowed them to strike with higher force. The latter is true for both genders, however, since male hands and arms are (generally) larger, this could contribute to higher striking forces. Participants experienced "more control over the sound", and felt it "easier to produce consistent handclaps" while wearing the gloves. However, for the XXL-size glove, many participants felt they had "less control" over their handclaps. The results showed larger variations within the

XXL-group (Figure 3). However, again, this could be attributed to differences between male and female participants (i.e., comfortable striking force, hand size, etc.).

Differences between the gender groups could also be attributed to the provided glove model, which was designed for male adults. This brings forth an important limitation of our experimental design, as no female glove model was made available for simplification purposes. Furthermore, it can be acknowledged that the glove sizes nor the participants' hand dimensions were verified by physical measurements. This brings uncertainties to light. We can only assume that the gloves had a better fit for male participants. We also do not know to what extent the gloves used in our experiment are representative of "leather gloves" in general (e.g., with respect to their stated size compared their actual physical dimensions, quality of materials, durability, etc.). A study by Repp reported no significant differences between gender groups with respect to handclap amplitudes and spectral contents. Inter-individual differences groups were mostly associated with hand configuration [14]. It might be more challenging for participants to maintain the targeted hand configuration when gloves are of an inappropriate size. In future research this could be explored in greater detail.

The second beneficial effect the authors discovered was the reduced variability. By utilizing leather gloves, the standard deviation at low frequencies (63 Hz and 125 Hz) was lower than for the remainder of the audio spectrum. Across the full frequency range standard deviations were lower when wearing leather gloves. This is a finding with particular significance, as it points towards opportunities of obtaining room impulse responses with less variability, containing a higher decay range, than would be possible with simple handclaps.

When considering measurement of room impulse responses by means of handclaps, it is important to consider uncertainty. The ISO 3382 prescribes measuring three decays per source–receiver combination when using the interrupted noise method [20]. When using handclaps, measurements could be carried out faster than with electro-acoustic sound sources. It seems relevant to know more about the variability of handclaps over multiple repetitions. As an example, Figure 4 shows the moving standard deviation of handclaps, determined for the 125 Hz octave band over a growing number of handclaps. Two participants had prior experience with handclaps for room acoustic measurements, and have been emphasized in the data display for this reason. As can be seen in Figure 4, when the total number of claps is small, SD is larger than with greater numbers of handclaps. For simple handclaps, after 10 handclaps, the SD stabilizes; i.e., additional handclaps will not further reduce variability. When comparing the leather glove handclaps to handclaps without gloves, for the 125 Hz octave band, (1) lower inter-subject variability was found, (2) SD reached a stable and lower value with fewer handclaps, and (3) participants who were experienced in utilizing handclaps for room acoustic measurements demonstrated the lowest variability among the participants in this study. The latter observation gives an indication that handclaps with leather gloves, when produced by a trained individual, produce impulsive signals with better usability for room acoustic measurements than simple handclaps (i.e., by targeting the largest possible decay range, particularly in the lower frequency bands). To what extend this observation could affect results of room acoustic parameters, is unknown.

In conclusion, wearing leather gloves leads to substantial improvements of frequency content and apparent improved repeatability of handclaps for acoustic measurement of room impulse responses. This finding further increases support for performing room acoustic measurements by means of handclaps. Future research must investigate the effects of leather glove handclaps on the resulting room acoustic parameters.

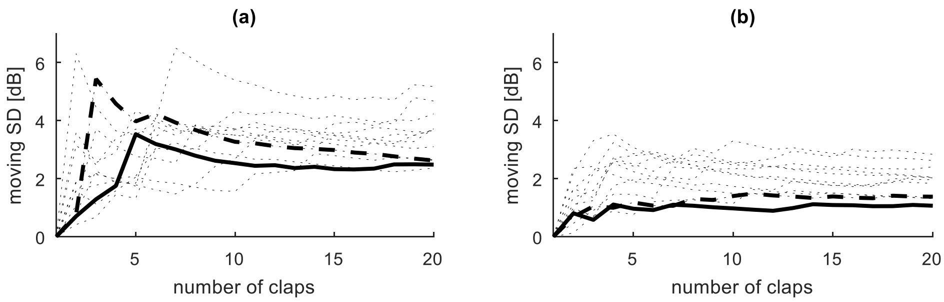



**Figure 4.** Moving standard deviation over the number of handclaps, for all participants, for the 125 Hz octave band. The data of the two participants who have experience in performing room acoustic measurements utilizing handclaps are emphasized with a thicker line type. The left panel (**a**) gives results without the glove (simple handclap with the A1+ configuration). The right panel (**b**) gives results for the best fitting glove size per participant (see also Table 2).

**Author Contributions:** R.d.V. supervised the measurements, analyzed the data and wrote part of the manuscript; N.M.P. provided suggestions and wrote part of the manuscript; G.E.S. provided suggestions, reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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