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Experimental One-Sided Choppers Relating Neuromuscular Human Abilities to Heart Rates and Technological Evolution

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Abstract: The length of time it takes to experimentally make one-sided choppers, as found in the fossil record, bears a linear relationship to the knapping process of fabricating them. In addition, this temporal frame appears to be related to human heart rates measured as beats per minute, which act as a physiological metronome. We achieved these observations, assuming that any paleolithic one-sided chopper has the information needed to estimate, quantitatively, the number of strikes on it. The experimental data allow us to establish the total timing needed for the standard fabricating of any one-sided chopper. We discuss issues derived from these experimental results, showing the evolution of human neurological abilities from 2.4 million years ago to the Modern period via the duration of time needed for making one chopper to that needed to play a 19th-century music score on a piano. Given that the neuronal and physiological distance between both actions differs by a factor of 6, we propose the concept of "technome" to measure human evolution by using methodological homogeneous metrics applied to these two human technologic objects: the chopper and the piano.

Keywords: hominins; chopper; heart rate; piano playing; technome

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Citation: Parra, I.; Morales, L.; Mar, J.; Carbonell, E. Experimental One-Sided Choppers Relating Neuromuscular Human Abilities to Heart Rates and Technological Evolution. *Humans* **2023**, *3*, 193–202. https://doi.org/10.3390/humans3030016

Academic Editor: Kevin M. Kelly

Received: 22 June 2023
Revised: 26 July 2023
Accepted: 28 July 2023
Published: 3 August 2023

1. Introduction

The role of lithic tools as a key driver of the adaptive changes that occurred during the late Pliocene and early Pleistocene eras is found in much of the literature [1]. Evidence is consistent about the role of lithic tools in the hominins' food supply and in the increases in their body size. Thus, research has focused on the training process that allowed hominins to ascertain the know-how to produce tools, such as choppers, in a systematic, repetitive, industrial way [2,3].

While many hominins have been viewed as under evolutionary pressure to create and use tools [4], those of genera *Pithecanthropus*, *Australopithecus*, and *Homo* display, from 3.3 million years ago a long, a constant and unique paleontological–archaeological record of continuously improved lithic tools [4,5]. These instruments made by hominins have been found by archaeologists to be morphofunctional, exosomatic artefacts produced in a similar way, and they have been associated with the evolution of human cognition [6,7].

The long transition, at least from 3.3 to 2.4 Ma (million years) ago, from less accurate to shorter, ordered, and efficient chains of strikes that produced serial lithic tools culminated in one-sided choppers at a very critical period of challenging climate change controlled by new global dynamics in the state of water. These Plio-Quaternary climatic changes, namely, the glacial–interglacial cycles [8,9], built up the Eastern African scenarios where the hominin bands [10,11] evolved and where there is evidence that, besides being associated with functions such as battering, the one-sided chopper is related to obtaining high-quality proteins derived from efficiently scavenging the long bones of big mammals.

Therefore, we present a set of pebble choppers, not only experimentally produced, but also analyzed by the authors according to methods for quantifying the timing associated with the repetitive, mechanical process for producing early choppers. This timing is an actual quantitative signal that we can reproduce, analyze, and validate for those early humans. We have both chosen and centered our inquiry on one-sided choppers, the very first serial instrument made by hominins, because the total number of flakes chipped off the pebble in the fabricating of each lithic tool can be established without any overlap of strikes made during the reduction process. Before this apparently simple tool appeared, there is a fossil record of pre-choppers tools showing that one-sided choppers resulted from an evolutionary technological trend [12,13] in a particular hominin group (*Pithecanthropus*, *Australopithecus*, and early *Homo* species) coinciding with and/or triggered by climate change [8]. Although these first serial industrial lithic tools are not prehistoric instruments for playing music in the sense described by d'Ericco [14], they can be studied with the use of musical techniques.

The need to obtain precise metrics in counting the number of strikes on the chopper arises from clinical evidence [15] showing that rhythmic stimulation has profound effects, as in coordinated sensory input to entrain timing functions, especially in motor control; rhythm provides temporal structures through metrical organisation, predictability, and patterning. Reflexively–the repetition of nearly identical mechanical movements–produces a repetitive series of sounds, such as those made by the short discrete chains of successive strikes involved in the act of fabricating lithic tools. The intangible result is a sequence of percussive sounds—that is, a rhythm pattern relating sounds to arm movements.

2. Materials and Methods

As the aim of this study was to quantify the entire process producing early one-sided choppers through metrics relating time and number of blows, we applied an actualistic approach [1,16] to reproduce fabrication of Pliocene-early Pleistocene artefacts. We analyzed this process by using musical and statistical methods. External validation compared the results of our experiment with actual choppers to examine how well they were fitted to the original [17,18]. We contend that the finished early one-sided chopper represents the summation or paleo-score record of the sequence of blows and sounds necessary for its production. It is assumed that any one-sided chopper in our experimental set adheres to the same operative chain for one-sided chopper production as existed between approximately −2.5 million and 0.75 million years ago (Ma) [4].

Our method of fabrication employed a level of technical knowledge consistent with that existing during Mode 1. It consisted of a continuous chain of successive strikes from a stone hammer leveled against a rounded pebble stone; the number of blows struck were intended to produce a serrated-continuous cutting edge on one side of the lithic platform used as a pounder [5]. We measured the time (tempo) speed at which our one-sided choppers were produced. The rhythm refers to patterns of temporal distribution of actions which resulted in sounds [6]. These have been transcribed into explicit divisions of time and classified in intervallic time systems. In this paper, we use only the total time needed to finish each experimental one-sided pebble chopper. Other characteristics of sound, such as rhythm, pitch, and intensity, are not considered.

To establish a time standard for the singular physical action of striking early one-sided choppers, an independent set of heartbeat profiles was employed according to standard statistical methods. We generated two sets of random values for time between heartbeats in modern humans and chimps from an inverse Gaussian distribution with parameters (mean and standard deviation) obtained from the literature [19–21]. This function returns the inverse of the normal cumulative distribution for the specified mean and standard deviation [20] and allows us to obtainin the samples for humans and chimps by incorporating a random parameter for probability (Table S4).

2.1. The Experiment

In 2008 and 2009, we employed a set of 101 chopper tools in 5 rounds of field experiments conducted by 3 different subjects at 3 different times in 3 different locations within Spain. The subjects were asked to make one-sided choppers from raw materials that they selected from the environment surrounding the experimental workstations.

The same trained musician of our team (LM) transcribed the sounds produced during the experiment in the field and the laboratory into modern musical notation. Additionally, the sounds produced in fabricating the lithic tools were recorded by means of a digital audio system. The total resulting audio data were further analyzed by means of Windows Media Audio (WMA) software and a digital metronome. Each trial was measured according to the following parameters:

a. Total time required to make a one-sided chopper measured in seconds (WMA);
b. Tempo measured in beats per minute (BPM) (digital metronome and WMA);
c. Number of blows and silent intervals involved in making a one-sided pebble chopper tool (noted in standard musical notation). The quarter note was taken as a basic unit of measurement (bpm = 1 quarter note).

Every strike was represented by a quarter note, and every silent interval by a rest. This resulted in a score being produced for every chopper tool, wherein the 3 parameters were recorded. Every score was further processed in Excel and with KaleidaGraph software (KaleidaGraph v.3; Table S1 and Figure 1).

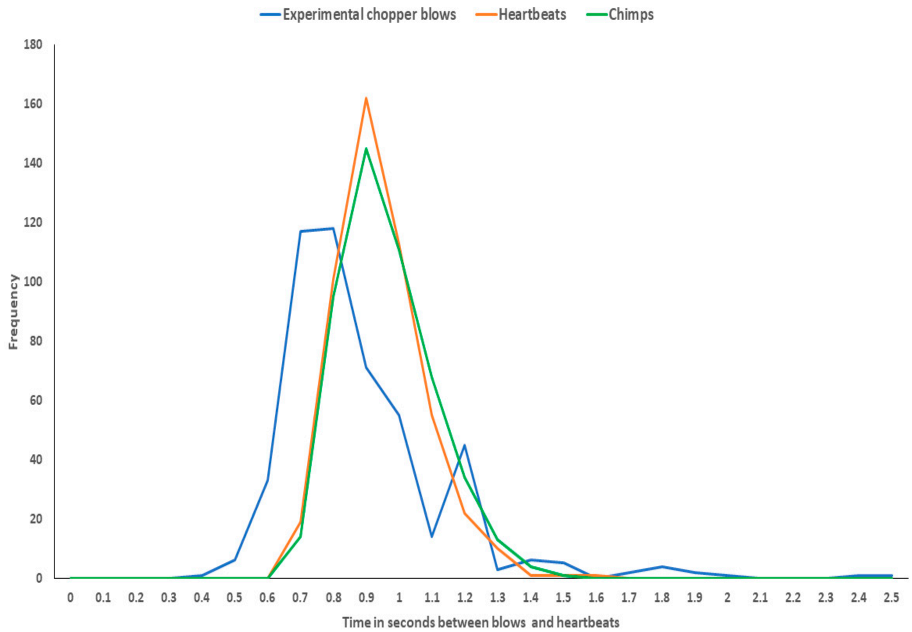

Figure 1. The human heart as the most probable metronome controlling the temporal frame at which experimental one-sided choppers were made. It is shown that chimp heart rates display almost the same beats per minute (BPM) as human heart rates (HHR).

2.2. Analysis

We regard every blow or strike in the operative chain of strikes involved in producing choppers as one beat or element of a cumulative group, where the total sum of beats or elements yields the total time of execution or fabrication of the lithic tool. Using regression analysis, we quantified the time needed to produce a chopper as a function of the number of strikes. Additionally, the time span between beats in the operative chain has been measured.

If: β = blow or silence indicating a given temporal interval;
t = time observed during the experiment,
then:

$$\Sigma\beta t = \beta 1 + \beta 2 + \beta 3 \ldots\ldots \beta n;$$

$t > 0.45$ s.

We obtained two series of data: the total production time of each lithic tool and the rhythms attendant to its production. As noted in Table S1, we measured with accuracy to hundredth of a second, such as 0.45 s, the timing involved in the fabrication of choppers.

According to this method, we can, for example, obtain within a matrix of 485 strikes, 4 time-sound data from chopper nº22, which displays a constant speed (tempo) of 84 BPM including a pause of 84 BPM between strike nº2 and nº4 (Table S1).

Notation of times in the lab: (60/84 + 60/84 + 60/84 + 60/84).

Temporal sum of experimental chopper 22 = 1st blow 0.715 s; 2nd blow 1.42 s; 3rd blow 2.14 s; 4th blow 2.85 s. Total = 2.85 s.

2.3. Validation

Figures S1 and S2 (Supplementary Materials) show the goodness of fit with actual choppers. If the results are adjusted to original artefacts, we can assume that the fabrication process followed the same steps and therefore use it to generate information, through long temporal intervals, about the determinants that drove hominins to incorporate the results into their behavior.

3. Results

In 2008 and 2009, we produced a set of 101 choppers in five rounds of field experiments conducted by three different subjects at three different times in three different locations within Spain. The subjects were asked to make one-sided choppers from limestone raw materials previously selected from the site surrounding the experimental workstation.

The general principle for knapping pebbles to produce serial lithic tools is the following: the hammer must be harder than the knapped pounder or base; the raw materials, quartzite and limestones, used in this set of experiments as hammers and bases are vastly available within the majority of Spanish archaeological sites; from a technical point of view, we use the same structural protocol as did early hominins: when quartzite hammers are used, the pounder being knapped is a limestone pebble, but when limestones are used as hammers, the chosen base must be a softer limestone pebble.

Thus, Experiment 1 (Table S3) was carried out on the morning of 14 November 2008 on the river embankment dating from the Quaternary Period in Tarragona. Subject A (EC, a male co-author of this paper) used limestone rocks to make six choppers with a single quartzite hammer. He is highly trained in lithic technologies and has more than 45 years of experience in reproducing prehistoric lithic instruments as an experimental archaeologist.

Experiment 2 was carried out on 21 March 2009 at the University of Tarragona by Subject A. Here, limestone rocks were selected in advance by students. Additionally, two different hammers were used: one in limestone for producing choppers 7 through 15 and 25 through 57; and one in quartzite for tools 16 through 24.

Experiment 3 was carried out on the morning of 23 June 2009 in the archaeological park of Atapuerca. Quartzite stones were collected in advance at the nearby fluvial terrace dating from the Tertiary Period. Subject A made a second selection in terms of workable sizes immediately before the percussion of the stones. Three quartzite hammers were used here, as the two earlier examples broke during the experiment with choppers 58 through 82.

Experiment 4 was carried out by Subject B (female) on the afternoon of 23 June 2009 in the archaeological park of Atapuerca. From similar pre-selected stones, Subject B made choppers 83 through 92 using a single quartzite hammer.

Experiment 5 was performed by Subject C (female) at the same workstation as subject B approximately 15 min after subject B finished her rounds of percussion. A single quartzite hammerstone was used in the fabrication of choppers 93 through 101. Both subjects B and C had far less experience in reproducing ancient lithic instruments than subject A.

Out of a total of 101 pebble choppers, 9 (8.9%) were broken during the experiment. Production of the 92 one-sided choppers required a total of 485 strikes (Table S1).

1. It has been observed that a chopper may be produced in less than 15 s. In our experiment, the observed temporal limits for making any given chopper were a minimum of 3 s and a maximum of 12 s, regardless of the level of previous experience or the gender of the subjects striking the stones.
2. We applied linear regression methods to predict the time spent producing each chopper as a function of the number of blows. The resulting general equation was as follows:

$$\text{Time of execution} = -0.760 + 0.988 \times \text{Number of blows.} \quad (1)$$

This analysis did not distinguish whether the chopper was made by someone with or without experience. The regression equation 1 explains 85.9% of the variation in total time.

Counting the blows in the production of any experimental chopper displays a linear equation relating both time and strikes. Therefore, counting the number of flakes observed on any fossil of a one-sided chopper allows us to obtain, by using the linear equation derived from our experimental matrix, the total time of execution of that lithic tool.

We assume that temporal fabric differences ($p > 0.001$) among knappers unveiled by ANOVA statistical analysis of the experimental results (Tables S1 and S2) well-reflects the operative structure of early hominin groups and their mixed demographic structure, including females and males, adults and children. The older and more expert the subject, the faster the lithic tool is finished, and here, more age equals to more experience; in this way, the experienced male subject A did produce one-sided choppers at more rapid intervals than both the less-expert females subjects B and C; nevertheless, the final products, whatever the experience of the maker, are both average and functional one-sided choppers (see images at Figures S1 and S2).

3. We found that the time and number of strikes spent making a chopper appears to correlate with the human heartbeat (Figure 1). To show the relationship between the timing involved in the fabrication of choppers and the cardiac rhythm, we compared the timing of our experimental chopper blows with a completely independent set of modern human heart rate (HHR) profiles. For the profiles, we used a published survey of 7746 healthy male Frenchmen, aged 42 to 53 years, carried out from 1967 to 1972 [1]. Then, 485 random values from the observed HHR data were processed through a Normal Inverse Gaussian (NIG) function [19,21]. They are shown in Table S4.

4. Discussion

As both genera, *Pan* and *Homo*, display analogous heart rates [20], one can assume that the heart rates of modern humans do not differ markedly from those of the early species of our genus.

When we take into account the heart rates of modern humans, we obtain temporal boundaries that appear to be related to our set of experimental strikes (Figure 1). Significantly, scholars have already noted the role of the heartbeat—whether high or low—in framing neurological reactions of the human brain [22]. Our experiment shows that the timing of the production chain for a one-sided chopper (min–max 45–120 beats per minute (BPM)) is related to a physiological temporal frame, which we postulate to be that of the human heartbeat (min–max 50–120 BPM, with a mean of 68 BPM and standard deviation [SD] of 9.1).

Given this, it appears that early humans produced choppers through short, rapid sequences of strikes at a pace analogous to their heartbeat. Overwhelmingly controlled by fast and short neuromuscular efforts, these working sequences yielded the first serial tools through discrete and sustained strikes accompanied by their instantly resultant sounds, paced at almost one beat per second (Figure 2 and Table S1).

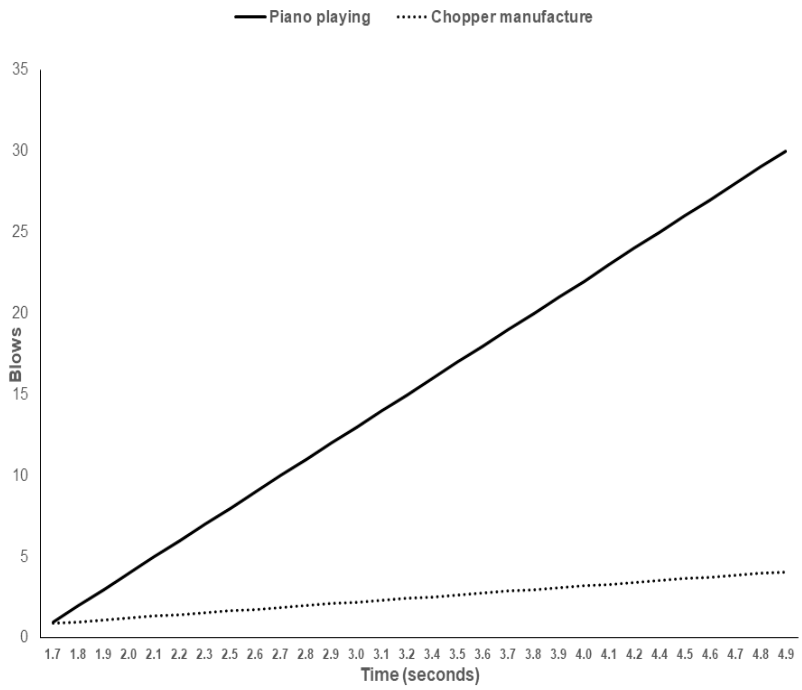

Figure 2. Relationship between number of blows and duration in seconds during piano playing (Johann Baptist Cramer sonata 1) and one-sided chopper manufacture: in 4 s, the one-sided chopper is fabricated by 5 strikes or percussion beats; meanwhile, on a piano, a classical score can be performed in 30 strikes or beats.

Our experiments reveal in a measured way the simple sound patterns as actually heard by early humans during the fabrication of industrially similar lithic tools.

Thus, we can postulate that these quick sequences of strikes and sounds developed precise causal neurological relationships in the hominin brain, as they were constantly repeated and heard by early and modern humans over a span of more than two million years from approximately −2.5 up to 0.01 Ma (million years) since one-sided choppers from Early Holocene times have even been found in fossil records in both North and South America [23–25].

During more than 0.75 Ma, lithic tools predating Olduwai one-sided choppers [4,26] strengthened the causal relationship between arm movements and the size and weight (depending on hardness and density) of both the lithic hammer and the lithic platform from which short sequences of strikes yielded flakes. Thus, the one-sided chopper appears to be the final, and optimal, product of a continuous experimental chain of trial-and-error strikes on stone materials, producing flakes and other pre-industrial serial lithic tools [12]. One-sided choppers, as the final result of the chain of strikes, became the first lithic tools made in an industrial way, where a few strikes produced a final and powerful multi-use tool.

Thus, we suggest that these serial sounds of work probably acted as sensory attractors [27], helping to improve the coordination of the nerve–muscle control systems through not only the broadcast but also the auditory reception of these short sound chains. The repeated act of striking stone against stone produces a sound pattern. The time-bound sense of anticipation related to the production of each sound regulates the action of the arm striking the hammerstone on the stone platform [11]. From examination of the clinical evidence regarding neurological therapies, it has been determined that sounds have a strong impact on the arousal and priming of the motor system to set it into states of readiness through reticulospinal pathways on the brain stem and spinal cord level [15,22].

Moreover, it has also been observed that rhythm as a temporal ordering process creates anticipation and predictability [27,28]. Additionally, sound patterns provide temporal structures that aid in predicting, patterning, and regulating physiological and behavioral functions. These, in turn, exert a significant influence on core elements of the perceptual mechanisms that form and shape the human memory.

Thus, to obtain a visual understanding of human evolution by means of both the method and results we have described, we compared the 4 s needed to make a one-sided chopper in five strikes with the number of strikes produced in 4 s by the coordinated arm, hand, and finger movements of a trained musician on the mechanical keyboard of a piano. We selected nineteenth-century music [29] to be played on the piano because it allows for the performance of very quick, coordinated, mechanical movements by means of neuromuscular action exclusively.

The comparison shows that the evolution of the brain, along with the evolution of technology during more than 2.5 million years, has increased by a factor of 6, the number of strikes that can be produced by a trained person in 4 s (Figure 2). The piano is played with such a number of strikes in a relatively short period of time, in part, because our modern brains are capable of such activity. Commensurate with this level of brain function, the highly skilled work of piano makers has produced a musical instrument of percussion consisting of hundreds of wood and metal sub parts [30] that can be successfully operated by a trained musician's coordinated arm, hand, and finger movements.

5. Conclusions

Conceptually, our method and analysis of how rapidly one-sided choppers were made provides one metric bridge, the "technome", between both the early and modern human ability to produce ordered and serial sounds at progressively faster rates (Figure 3). Given that we found a magnitude of a factor of 6 between both the early and modern ability to produce discrete and ordered sequences of rapid strikes or sounds, we propose that the technome maps the temporal evolution and changes of human abilities through material and immaterial objects produced by men.

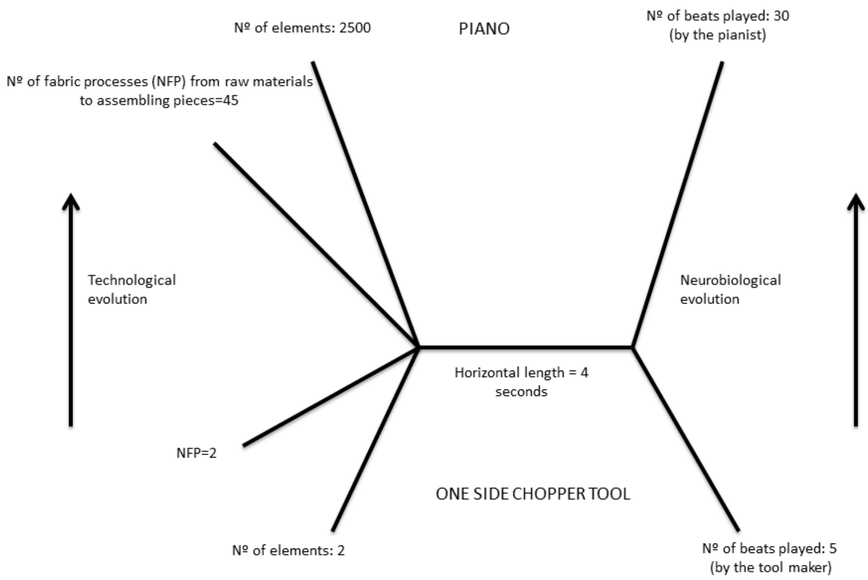

Figure 3. Description of technome.

The paired "technome" of a one-sided chopper and a piano shows different metrics summarized through their ratios that display the magnitude of the human evolutionary trend: on the neurological right side, Figure 30/5 = 6 measures the ratio between the brain–arm–eye system of both early hominins and modern humans to produce ordered sequences of striking sounds during 4 s. The technological side of the Figure 2500/2 (number of elements) and 42/2 (number of fabric processes) shows how many times the number of elements grew during the early prehistoric and modern periods and the equivalent number of fabric processes that grew through time, from simple lithic serial technologies to complex instruments of percussion that optimize the ability of the brain to coordinate every finger of both hands at short time spans, i.e., 4 s.

In our case, the technome of the pair of objects consisting of a one-sided chopper and a piano score allows us to propose that hominin brains cultivated human-like abstraction during the fabrication of early stone tools. This abstraction was derived from the neuromuscular effects of the repeated stone strikes involved in the rapid, ordered sequence of arm–eye movements that produced early industrial choppers, as well as subsequently more complex instruments, along the human evolutionary path [31,32]. This implies the emergence of a complex cause–effect memory, as the chain of working strikes and their resultant sounds relates to specific nervous responses and is linked to muscle-related arm movements with very precise mechanical effects. These, in turn, produced sensory inputs that built up sequences of temporal cause and effect (human-like abstraction) that were oriented towards reproducing similar lithic instruments. Over a period of more than two million years, the repetition of sequences of rapid chains of arm movements with their related strikes and sounds has aided and contributed to the emergence of memory as we know it today [33], as it is used by the modern pianist who rapidly plays/strikes chords.

In this way, the manufacture of pre-chopper tools, followed by more complex tools such as one-sided choppers, gave rise to strong cause-and-effect relationships, not only at the visual level of tool-making but also at the level of aural memory [34], the assimilation of sound patterns, and, therefore, the industrial production of very similar lithic tools. Thus, the modern neurological ability to play rapid musical scores is deeply rooted in the ability of early hominins to produce quick and ordered sequences of strikes/-sounds that resulted in the industrial making of one-sided choppers.

Finally, we intend to develop in this line of research in the future, focusing on technome metrics massively used on different prehistoric and modern objects, and by accurately measuring the time required for the fabrication of hand axes dated between 1.8 Ma to 0.001 Ma. Temporally, after chopper one-sided chopper tools, these hand axes successively correspond to the next technological and chronostratigraphical stage of human evolution. They are much more complex lithic tools since their industrial fabric requires dozens of minutes to be produced, implying several and continuous changes of spatial position, looking for the best angles of percussion in order to obtain both continuous and sharpened edges around the same lithic base. In this way, we would further contribute, progressively, through the production of more quantitative data, to our collective knowledge of the singular emergence of hominins' techno-operative memory.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/humans3030016/s1, Table S1: Database of the experimental one-sided choppers; Table S2: ANOVA test showing temporal fabric differences among the three subjects (A, B, and C) during the experiment; Table S3: dates of the experiments, locations, level of expertise and sex of knappers and hammer raw materials; Table S4: Database of ING (inverse normal Gaussian) distribution for HHR and experimental strikes of each one-sided chopper; Figure S1: experimental chopper 1; Figure S2: experimental chopper 2.

Author Contributions: I.P. Designed research; performed research: I.P., L.M. and E.C.; analytic tools: J.M., I.P. and L.M.; analyzed data: J.M., I.P. and L.M.; Wrote the paper I.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is available in Supplementary Materials.

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

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