Cultural Transmission and Technological Transitions during the Late Paleolithic in Korea

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The onset of the Late Paleolithic period in Korea, represented by the appearance of stemmed points and blades, was a key event in the dispersal of modern humans in Northeast Asia. Previous studies have mainly focussed on possible origin locations of these new technologies. The specific cultural processes of the appearance stemmed points and blades has rarely been considered. We investigate the cultural processes by applying a cultural transmission framework to investigate the social contexts of the emergence of these new technologies. Our main question is: what was the dominant mode of cultural transmission during this time of technological innovation in the Korean Late Paleolithic? Following Bettinger and Eerkens (1999), we evaluated models of guided variation and indirect bias using data from Korean assemblages containing stemmed points. To evaluate these models and understand the transmission processes, we computed correlation coefficients and coefficients of variation (CV). We found that information about the new technology was likely transmitted via guided variation with small impact of indirect bias. Some attributes including length and width were transmitted with less variation while other attributes appear to have more variation. Our results suggest that the dominant mode of cultural transmission for the earliest stemmed points was guided variation . We assume that individuals or groups developed stemmed points by experimenting with existing blade technologies and then copied crucial parts of a successful model to ensure the quality to optimize tool usage. As a result, the shape of stemmed points became more standardized among their social groups.

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# Introduction

The application of evolutionary theory to archaeological research has been productive for the investigation of technological transitions and related human behaviors in the remote past (Bettinger et al., 1997; Bettinger and Eerkens, 1999; Dunnell, 1980; Lipo et al., 1997; Mesoudi and O’Brien, 2008). For example, archaeologists have used evolutionary theory and methods to study human behavioral ecology, cultural transmission, artifact phylogenetics, and niche construction in the past (Garvey, 2018; O’Brien and Bentley, 2017; Riede, 2010). In this paper we used cultural transmission theory to investigate technological transitions during the Korean Late Paleolithic. The primary technological innovation is during this time was the appearance of new tools such as stemmed points and blades. The appearance of these new lithic technologies may represent the first arrival of modern humans in this region, and so they may also represent a key event related to modern human dispersal throughout East Asia (Seong, 2009). Previous studies on the origin of stemmed points have mainly focused on their possible origin locations, connecting Korea with global patterns of modern human dispersal. However, questions about the specific cultural processes and social contexts of this technological change in Korea remain largely unanswered (Bae et al., 2017; Bae, 2010; Seong, 2008). In this research, we apply a cultural transmission framework to investigate the social contexts of the emergence of new technologies in the Korean Late Paleolithic. Our main question is: what was the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Additionally we ask: Do the modes of cultural transmission vary over time and space? We consider three possible modes of cultural transmission: guided variation (trial and error), indirect bias (copying others), or a combination of the two. Our results have implications for determining if these new technologies were introduced from outside of the Korean Peninsula, or if they were locally, independently developed.

# The Late Paleolithic of the Korean Peninsula

The onset of the Late Paleolithic period in Korea is marked by the appearance of stemmed points around 40-35 ka. The stemmed point is a projectile point made out of an elongated flake or blade with slight retouch on the proximal end to shape an acute tip, and on the distal end to make a stem, which connects to a shaft. The stemmed point was the first composite tool type appearing on the Korean Peninsula, and represents new hunting strategies there, as well as other adjacent regions where it appeared later (Lee and Sano, 2019; Seong, 2008). Stemmed points, combined with blade technology, multi-stage production sequences, and evidence of being resharpened and reused, are important aspects of the Late Paleolithic technological innovations in Korea because these features are rarely seen in earlier periods (Bamforth, 2009; Chang, 2013; Seong, 2015). Currently the earliest stemmed points in Northeast Asia are from Yongho-doing site in Korea dated to 38.5ka and made on elongate flakes (Bae et al., 2017; Seong, 2015, 2009). After their first appearance in Korea, the stemmed points spread to the Japanese archipelago (Chang, 2013).

Previous studies of the Late Paleolithic technological transitions in Korea have mainly focused on the possible origin locations of stemmed points, as part of the discussion of the timing and routes of modern human dispersal in eastern Asia. The debate about the origin of stemmed points can be summarized into two competing models: *in situ* evolution (Seong, 2009) and heterogenic migration (Bae, 2010). The *in situ* model claims that stemmed points and other Late Paleolithic assemblages including blade industries autonomously emerged in the Korean peninsula, as a form of convergent evolution (Seong, 2009, 2008; Seong, 2006). To support his claim, Seong (2009) examined the blade-to-flake ratios of stone artifact assemblages in South Korea. In his view, the blade industry represents a new technology while flakes indicate a continuously-used existing one. He argues that the increased ratio of blades in stone artifact assemblages during the Late Paleolithic shows an expansion of the new technology after its local invention. In addition, Seong claims that increased numbers of stemmed points over time, and standardization of their shape, supports the prominance of gradual, local, evolutionary processes in the emergence of new technologies.

In contrast, the migration model argues that the new blade industry, including stemmed points, and the earlier simple flake tool tradition, including large cores, polyhedrals, choppers and handaxes, came from different origins outside of the Korean peninsula (Bae et al., 2013; Bae and Bae, 2012; Bae, 2010). While the *in situ* model claims that the heterogenic character is the result of indigenous development, the migration model proposes that it is the result of the continuous influx of modern human populations from both north and south. Specifically, the blade technology is claimed to have been introduced from Siberia, Mongolia, or other regions of northeast China following the Liaohe and Sunghe rivers around 35 ka BP, while the simple flake-tool tradition came from southern China (Bae et al., 2013). The migration of people from the southern route is supported by genetic studies of the Y chromosome, indicating that the O3-M122 M122 haplotype originated from southern East Asia and moved to northeastern Asia, including Korea, at 30-25 ka BP (Shi et al., 2005). Bae et al. (2012) assume this southern migration could be related to paleoenvironmental fluctuations during the MIS 3 to 2 transition, which made the Yellow Sea/West Sea region open.

Lee (2013) argues that the transition to the Korean Late Paleolithic might be more complicated than either models of migration or *in situ* development. He partly agrees with the *in situ* model that simple flake tools had continuously been used in Korea as the result of ancestor-descendant relationships, under conditions of low effective population size. With regard to the blade industry, he claims that low degrees of uniformity and small quantities of blade-associated toolkits indicate an origin outside of Korea, perhaps resulting from trade or migration. We explore these three options, *in situ*, migration, and a mixture of the two, by measuring transmission biases in assemblages of stemmed points.

# Cultural transmission and transmission biases

To measure transmission biases in tool-making, we draw on Darwinian evolutionary theory. This body of theory has helped archaeologists understand a variety of technological innovations and related human behaviors, for example using human behavioral ecology, phylogenetics, cultural transmission theory, and niche construction theory (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Dunnell, 1980; Eerkens and Bettinger, 2008; Lipo et al., 1997; Mesoudi and O’Brien, 2008; Richerson and Boyd, 1992). Cultural evolutionary approaches are effective at explaining cultural changes using mechanisms of inheritance, variation-generating processes, and selection. The mechanisms are similar to biological evolution, but in cultural systems they have unique and distinctive properties. Social transmission strongly affects these key evolutionary processes (Whiten, 2017), and can occur through various learning processes, such as stimulus enhancement, emulation, imitation, and teaching (O’brien and Lyman, 2000; Schillinger et al., 2014). We focus here on how different social contexts can result in different modes of social transmission of tool-making skills among hunter-gather populations.

Cultural transmission theory holds that information about social and technological behaviours is acquired through interaction with other individuals and the environment (Boyd and Richerson, 1988; Richerson and Boyd, 1992). Individuals learn by themselves (e.g. trial and error), or from each other by sharing information. Information can be modified (also known as ‘biased’) depending on an individual’s transmission context and cultural repertoire. Modification of information can occur by recombination, loss, or partial alteration (Eerkens and Lipo, 2005; O’Brien and Bentley, 2017). Transmission biases can be important loci of changes in material culture, and can be influenced by the social contexts of cultural transmission (Creanza et al., 2017; Eerkens and Lipo, 2007; Heyes, 1994; Kendal et al., 2018; Lycett, 2015). These biases include guided variation (where individuals learn new behaviors through trial and error), content-based bias (where some aspect of the transmitted instructions, such as cultural preferences, makes them more likely to be adopted), frequency-based bias (where an individual is biased to choose particular behaviors based on their perceived frequency in the population, such as extremely popular or rare behaviors), and indirect bias (where a behavior is transmitted because of its association with other attributes, such as the prestige or skill of other individuals) (Boyd and Richerson, 1988; O’Brien and Bentley, 2017; Richerson and Boyd, 1992).

Bettinger and Eerkens (1999; 1997; 2008) have shown how two of these biases can be identified in stone artifact assemblages. Their research focused on metric variables of stone points during the introduction of bow and arrow technology in the Great Basin around AD 300-600. They equated guided transmission (where individuals learn new behaviors through trial and error) with high metric variation and low correlation between metric attributes. Conversely, they inferred indirect bias (where a behavior is transmitted because of its association with other attributes, such as the prestige or skill of other individuals) from less variation and more correlated variables. They found that artifacts in the new bow and arrow technology in eastern California have low correlations of basal width and mass, which they interpreted as a result of guided transmission dominating the introduction and spread of these tools. From these results, they inferred a social context in eastern California of distant and unfamiliar neighbors, with limited contact between groups to acquire technology directly. In this context of limited contact, they argue that the new technologies developed largely by trial and error. On the other hand, in central Nevada they found that metric variables are highly correlated, indicating that the bow and arrow was introduced and spread by indirect bias.

Following Bettinger and Eerkens’ framework, Garvey (2018) uses simulation to explore the degree of standardization represented by coefficient of variation (CV) values of projectile points from the US Southwest and westernmost southern High Plains. Garvey measured CV values for weight, thickness, width and lengths on two types of projectile points, Washita and Fresno points, from the Henderson site. She then computed simulated CV values according to three scenarios of different levels of transmission fidelity (i.e. CV = 10%, 5%, and 3%). The observed metrics of the archaeological projectile points are closest to the metrics of the simulated assemblage with 3% CV, which represents “extremely high-fidelity copying”. A CV of 3% is the Weber fraction, or threshold of human visual perception, with variation below this value being too subtle for people to notice (Eerkens, 2000). Garvey’s work shows how the cultural transmission of tool-making behaviours can be measured, simulated, and used to interpret the archaeological record.

Garvey and Bettinger and Eerkens inferred transmission processes from material culture because they were unable to observe them directly. Direct observations have been reported by Mesoudi and O’Brien (2008) who conducted experimental research using groups of undergraduate students to test the underlying assumptions of Bettinger and Eerkens’ study. They simulated model-based bias in projectile point making by providing the design of a model and information of the model’s prior success to their research participants. They also simulated guided variation by allowing their participants to explore their own designs. They observed that the majority of participants who were able to choose the previous design copied the most-successful model. Metric attributes of the points made when copied from successful models were more highly correlated than attributes of points made by trial and error. Mesoudi and O’Brien’s experimental results are important because they confirm the robustness of previous assumptions about cultural transmission biases, and validate the connection between material culture variation and cultural transmission biases.

# Modeling the social context of the appearance of stemmed points in the Late Paleolithic of Korea

Inspired by Bettinger and Eerkens’ approach, we use two contrasting transmission modes, guided variation and indirect bias, to investigate the spread of stemmed point technology during the Korean Late Paleolithic period. We propose a spectrum on which we can locate foraging groups and how they started to make stemmed points, depending on their degree of social isolation or social connectedness. On one end of the spectrum we have socially isolated groups who made stemmed points through guided variation; and on the other end of the spectrum we have socially connected groups whose knowledge of stemmed points derived from transmission processes dominated by indirect bias.

To contextualize this further, on one end of our spectrum we have socially isolated groups who stayed in physically remote places from other groups, or had unfamiliar neighbors with limited contact between groups. Our assumption for this social context is that individuals or groups acquired the technology of stemmed points by modifying existing flake tool forms through trial-and-error processes to solve problems relating to resource procurement (cf. Seong’s *in situ* model). If this social context was prevalent, we predict this trial and error behavior could have left a distinctive signature on the metric variables of the stemmed points. If trial and error was the dominant bias in the transmission of knowledge about how to make stemmed points, we expect that the morphological attributes on a stemmed point will be poorly correlated and show high variation within assemblages and between sites.

On the other end of our spectrum, we have socially connected groups that occupied places close to other groups or had regular contact with other groups. Relatively high degrees of social connectivity provide frequent opportunities for observing others and acquiring information. Individuals or groups learned the technology of stemmed points by copying a model from another individual or group. In this scenario, the model, or ideal, stemmed point is likely to have been a highly successful and frequently chosen one, and learners copy all information about the point design as a package. This implies a small number of locations, or a single point (perhaps from a source external to the Korean peninsula, cf. Bae’s migration model), where stemmed points first appeared and then spread from. In this social context, indirect bias is the dominant influence on transmission of lithic technology. If indirect bias was prominent in the Korean Paleolithic, we expect that stemmed points should be more standardized, and attributes on the stemmed points will be more correlated, and assemblages from multiple sites will show less variance between and within them.

# Materials and methods

## Materials and stemmed points chronology

After the first discovery of stemmed points at the Seokjangri site in the 1960s, around 300 have been found in nearly 30 sites across Korea ([Figure 1](#fig-map)). Most sites contain only a few points but a few sites have many more, such as Suyanggae (n = 55), Jingeuneul (n = 99), and Yongsandong (n = 38) (Kim, 2017). Among these stemmed points, we selected those that are unbroken from the tip to the stem. We excluded artifacts that were recorded as stemmed points but lack a stem. This resulted in a sample of 152 stemmed points from 23 assemblages unearthed from 20 sites spanning the period 40-17 ka ([Table 1](#tbl-sp-number)). The images of the stemmed points were obtained from published excavation reports and by direct photography during our research on local museum collections. We defined multiple assemblages in a site where artifact-bearing deposits were separated by culturally sterile deposits, or where distinct artifact-bearing stratigraphic units could be identified by major differences in the texture, color, and composition of the sedimentary deposits.

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| Figure 1: Korean Paleolithic sites mentioned in this study. |

Table 1: Total number of stemmed points found in sites and the number of stemmed points we used in the research. We excluded broken and unclear artifacts.

| Sitename | # of SP used in this study | Total # of SP |
| --- | --- | --- |
| Bonggok | 1 | 2 |
| Goryeri | 1 | 15 |
| Hwadaeri | 2 | 4 |
| Haga | 2 | 41 |
| Hahwagyeri | 1 | 2 |
| Hopyeongdong | 3 | 5 |
| Jingeuneul | 4 | 99 |
| Jungjangri | 1 | 1 |
| Jungmal | 1 | 1 |
| Juksan | 1 | 1 |
| Mungyeong | 1 | 1 |
| Songamri | 3 | 3 |
| Sinbook | 1 | 12 |
| Sachang | 2 | 2 |
| Seokjangri | 1 | 2 |
| Suyanggae location 1 | 42 | 67 |
| Suyanggae location 6 (Hajinri) | 67 | 86 |
| Wolpyeng | 5 | 6 |
| Yonghodong | 2 | 2 |
| Yongsandong | 11 | 38 |
| Total | 152 | 390 |

To analyze morphological change over time, we used previously developed chronologies that identify three phases in the Korean Late Paleolithic (Park, 2013; Seong, 2015). These chronologies were built on radiocarbon ages, and for sites without any, the presence/absence of blades, stemmed point blanks, and toolkit composition were used to assign assemblages to a phase. Following these previous chronological schemes, we divided the Korean Late Paleolithic assemblages into three chronological phases: 1) stemmed points made out of flakes and no blades in assemblages, 2) stemmed points made out of blades or flakes and the existence of blade in assemblages, and 3) stemmed points made out of blades and the existence of micro blades in assemblages ([Table 2](#tbl-korean-chronology)). Applying this division is necessary because some sites such as Yonghodong, Goryeri, Jungmal, and Mungyeong have no radiocarbon ages due to research limitations. Inferring ages for these sites by analogy to the technological sequences at sites with dates is necessary for making maximal use of the available archaeological data to increase our sample size. We arranged our 23 assemblages containing stemmed points in into these three phases to facilitate observations of change over time.

Table 2: Korean Late Paleolithic Chronology edited based on Seong (2015) and Park (2013). SP = stemmed point

| Phase | SP | Blades | Micro-blade | SP blank | Newly added raw materials | New changes | Radiocarbon ages |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 1 | Present | Absent | Absent | Flake | Higher-quality quartzite, Vein quartz | Increasing number of small flake tools, appearance of SP | ~35ka |
| 2 | Present | Present | Absent | Blade | Porphyry, Siliceous shale, Hitherto | Appearance of blades, increasing number of SP | 34-25ka |
| 3 | Present until 16ka | Present | Present | Blade, Micro-blade | Obsidian | Appearance of Micro-blade, microliths | 25-12ka |

Panel A of [Figure 2](#fig-raw-materials-by-phase) summarizes the amount of stemmed points in each chronological phase, and the distribution of raw materials across the phases. We exclude phase 1 from our analyses below because of the small sample size to compute correlations and CVs. Shale is the dominant raw material in both phase 2 and 3. In phase 3 there is an increase in the proportions of porphyry, driven largely by finds from Yongsangdong, and other raw materials. Panel B in [Figure 2](#fig-raw-materials-by-phase) shows the count of stemmed points by raw material type at assemblages with more than five stemmed points. Much of the raw material diversity comes from isolated finds, with those assemblages with more than five points showing high homogeneity in raw materials.

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| Figure 2: A: Three chronological phases of the Korean Late Paleolithic, and frequecies of stemmed points and distribution of raw materials in each phase. B: Frequencies of stemmed points by assemblage and raw material, for assemblages with five or more stemmed points. |

## Methods

Following the metric attributes used in previous studies of cultural transmission and projectile points, i.e. maximum length and width (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and Bettinger, 2008; Garvey, 2018), we used morphological attributes on the stemmed points to examine variations in shape and the relationship between each attribute ([Figure 3](#fig-labelled-schematic)). We obtained our morphological attribute data from landmark analysis of digitized images of stemmed points. Compared to traditional caliper measurements, morphometric data yields more easily interpretable numerical and visual outcomes than traditional caliper measurements (Buchanan and Collard, 2010; Cardillo et al., 2016; MacLeod, 2018; Okumura and Araujo, 2019; Petřı́k et al., 2018; Suárez and Cardillo, 2019; Thulman, 2012). We did not include weight and thickness as these measurements were not available to us. For the landmark analysis, we put a total of 11 landmarks on the outline of each stemmed point and computed distances between pairs of landmark coordinates to derive attributes for our statistical analyses. The landmarks we recorded are described in [Table 3](#tbl-landmark-abbreviations) and shown in [Figure 3](#fig-labelled-schematic). We used the point tool in ImageJ (Schneider et al., 2012) to capture the landmarks from images of the artifacts, and export them as XY coordinate data for further analyses.

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| Figure 3: Stemmed point from Yongsandong site with landmarks showing the attributes considered in this study and further research |

Table 3: Description of artifact landmarks used in this study

| Abbreviation | Description | Line segment on the image |
| --- | --- | --- |
| ML | Maximum length, tip to bottom, perpendicular to the length axis | 1-7 |
| BL | Body length, tip to the closest wing, perpendicular to the length axis | 1-3 or 1-10 depending on the artifact |
| TL | Tang length, the closest wing from the tip to bottom, perpendicular to the length axis | 3-7 or 10-7 depending on the artifact |
| SL | Maximum stem length, perpendicular to the length axis. Closer tang curve’s middle point from the tip to the most distant point of the basal end | 9-7 or 4-7 depending on the artifact |
| MW | Mid width, dimension from margin to margin at the mid-point of the length | 2-11 axis, perpendicular to the width axis |
| TW | tang width, dimension between each wing, perpendicular to the width axis | 3-10 |
| SW | Stem width, width of the basal end of the point, 5mm above the end | 5-8 |

Following Bettinger and Eerkens (1999) we computed Pearson’s correlation coefficients for all attributes on the stemmed points. The correlation of artifact attributes was proposed by Bettinger and Eerkens (1999) to be a key indicator of indirect bias during cultural transmission. This is based on the assumption that artifact-making was transmitted in packages of traits taken from socially successful individuals who were role-models. In their work, Bettinger and Eerkens (1999) interpreted correlation coefficient values of around 0.5 and higher as evidence of indirect bias, and lower values as evidence of guided variation. In this research, we examine correlation between attributes and explore other variables such as different phases, raw materials and assemblages.

We chose Coefficients of Variation (CV) to measure the variation among the measurements of the stemmed points. The CV is the ratio (usually expressed as a percentage) of the standard deviation to the mean. It has been used as a robust statistical method to calculate the degree of standardization, precision, equality, homogeneity, etc. in various disciplines (Ng, 2006; Panichkitkosolkul, 2013, 2009; Wang and Marwick, 2020). In archaeological studies, CV has been applied to measure the variation between artifacts and to test hypotheses about cultural evolutionary processes, including distinguishing between different types of learning biases affecting cultural transmission (Eerkens and Bettinger, 2001; Eerkens and Lipo, 2005; Garvey, 2018; Schillinger et al., 2014). As a guide to interpreting CV values, Eerkens and Bettinger (2001) claim that over 57.7% of the CV is the result of random production and below 1.7% is the by-product of using a scale or template. Among the various artifacts for which @eerkens2001techniques summarised CV values, the most comparable to stemmed points are Great Basin projectiles points, whose CV values range from 6-55%, with an average of 22%. Similarly, projectile points from the US Southwest have CV values ranging from 11% to 33% (Garvey, 2018).

Sample size can impact the accuracy of CV estimates (Kelley, 2007; Toebe et al., 2018; VanPool and Leonard, 2011). In previous archaeological studies, sample sizes for CV values has varied from five to more than a thousand artifacts (Bettinger and Eerkens, 1999; Costin and Hagstrum, 1995; Garvey, 2018; Kvamme et al., 1996; Rivals et al., 2009; Wierer, 2013). A variety of methods are available for improving the reliability of CV measurements when using small samples. For example, VanPool and Leonard (2011) proposed a “corrected CV”, for a smaller samples (i.e. n<25). Statistical research has resulted in several methods for computing confidence intervals on CVs to show uncertainty (Banik and Kibria, 2011; Curto and Pinto, 2009; Gulhar et al., 2012; Koopmans et al., 1964; Mahmoudvand and Hassani, 2009; McKay, 1932; Miller, 1991; Panichkitkosolkul, 2013; Sharma and Krishna, 1994; Vangel, 1996). Although we have a total of 152 artifacts, most of our analyses here involves comparisons of smaller subsets of this sample. For example to explore temporal and regional patterns we compared samples of well under 25 pieces. Given these relatively small sample sizes in our study, we used the corrected CV formula, which we have implemented here in a function in the R programming language for others to use. We also computed confidence intervals using method proposed by Sharma and Krishna (1994) to increase the credibility of the comparisons and be transparent about the precision and accuracy of our results (Albatineh et al., 2014; Kelley, 2007).

One limitation of previous work is the absence of a clear threshold value for interpreting CV values in terms of different transmission biases. Bettinger and Eerkens (1999) did not identify a threshold for CV values. Here we propose 25 as an approximate threshold to distinguish between the transmission biases. We used data in Bettinger and Eerkens (1999) to calculate CV values of Rosegate points from Monitor Valley, California, which was speculated by Bettinger and Eerkens to be the byproducts of indirect bias. With the exception of weight, the CVs for metric attributes on the Rosegate points is 17% to 24%. We believe higher side of the CV range of Rosegate points is appropriate as a threshold value for our research based on following reasons. First, variation is generated by small errors that are transmitted between individuals and the errors gets bigger through generations (Eerkens and Lipo, 2005). The duration of transmission process for stemmed points is much longer (in the order of thousands of years) than the case of Rosegate (in the order of hundreds of years in Fremont region) (Bischoff and Allison, 2021). Second, the errors are likely to vary by raw materials. Some raw materials, such as clay, are easier to control variation in while less controllable materials such as stone are likely to have higher CV values because of the relatively unpredictable nature of flaking (Eerkens and Bettinger, 2001). We assume that Rosegate projectile points were made from more finer grained raw materials such as flint compared to the raw materials for Korean stemmed points, which include shale, rhyolite, porphyry, etc. ([Figure 2](#fig-raw-materials-by-phase)). Third, the corrected CV calculation for small sample sizes that we are using tends to result in slightly higher values than compared to standard CV values (VanPool and Leonard, 2011). Given the tentative identification of this threshold value, we premised that CV values that are lower than 25 likely represent guided variation while CV values over 25 likley reflect indirect bias.

All data preparation, analyses and visualization were computed in the R environment (R Core Team, 2022). Our R code and data, including the original artifact images, are fully and openly available in our compendium (Marwick et al., 2018) online at https://doi.org/10.17605/osf.io/eb8mx to enable transparency and reproducibility (Marwick, 2017).

# Results

## Correlation coefficients

Our results show positive correlation between attributes throughout the Late Paleolithic (Panel A of [Figure 4](#fig-corr-analysis)). Some relationships such as BL and ML have stronger correlation (i.e. darker-blue points) than others (i.e. lighter-blue or almost invisible points). To understand temporal patterns in the modes of cultural transmission, we grouped our assemblages into the three Korean Late Paleolithic chronological phases summarized in [Table 2](#tbl-korean-chronology). Among the three chronological phases, we excluded Phase 1 from our analysis because there are only two complete stemmed points from Yonghodong and Sachang that date to this phase.

The correlations between attributes became stronger over time as we can clearly see in the Panel D of [Figure 4](#fig-corr-analysis). The median for Phase 2 is much lower than 0.5, which Bettinger and Eerkens (1999) interpreted as a threshold to evaluate transmission biases, while the Phase 3 median is close to the threshold. Based on this results, we assume that the earlier transmission for stemmed points was more likely the results of guided variation. On the other hand, Phase 3 could be more associated with indirect bias.

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| Figure 4: Correlation analysis by chronological phases in the Korean Late Paleolithic period. A. Correlation coefficient between attributes for all periods. B. Correlation coefficient between attributes for Phase 1. C. Correlation coefficient between attributes for Phase 2. The individual point represesnts correlation between two attributes. Some points are invisible due to their weak relationship. D. Correlation coefficient for the second and third chronological phases. The grey points represent correlation between two attributes. |

One limitation of this aggregation of all stemmed points in our sample into each chronological phase is that the sample consists of a relatively large number of assemblages with only 1-2 stemmed points. These isolated finds are ambiguous with respect to a local tradition of artifact making, so to further investigate temporal change, we focus only the four assemblages that have more than five stemmed points ([Figure 5](#fig-plot-cor-four-assemblage)). We assume these four assemblages are more likely to represent a consistent, recurring way of making stemmed points than isolated finds, and thus more relevant for comparing modes of cultural transmission of artifact making.The four assemblages include three from the Suyanggae site (SYG) and one from the Yongsandong site (YS). There are more variation in correlation coefficient in Phase 2 while the median values for the two assemblages from Phase 3 are similar to each other and close to 0.5. There is no clear pattern between assemblages. SYG1\_2 is from Phase 2 but it has the higher median than the assemblage from the same site in the later phase.

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| Figure 5: Correlation for assemblages with more than 5 stemmed points. Among the four assemblages, SYG1\_2 and SYG6\_2 are from Phase 2 of the Korean Late Paleolithic chronology and SYG1\_3 and YS\_3 are from Phase 3. The grey points represent correlation between two attributes. |

## Correlation between raw materials

To examine the impact of raw materials on the shape of stemmed points, we computed the correlation for different raw materials. We excluded raw materials that were used for less than three points. [Figure 6](#fig-corr-raw-ass) shows that the distribution of correlation coefficients is various depending on raw materials. Overall, the materials that used for more and equal to three points have high correlation coefficients. The stemmed points made from quartzite have highest correlation coefficients with narrow distribution. Acidic volcanic rocks are one of the highly correlated materials and individual correlations are skewed into two groups. Some of the correlations are even negatively related. Correlation values for porphyry stemmed points have a narrow distribution. Rhyolite stemmed points have wide distribution and some of the attributes are negatively related. Like acidic volcanic rocks, the correlation of shale stemmed points is also skewed into two groups. Tuff stemmed points have wide distribution with higher median value.

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| Figure 6: Correlation for raw materials that were used for making more than one stemmed poitns. The grey points represent correlation between two attributes. |

## Coefficient of variation

Panel A of [Figure 7](#fig-plot-cv-all-attributes) shows a relatively wide distribution of body length (BL) and maximum length (ML) while the other attributes are more similar and shorter (under 2.5 cm). Among these attributes, stem width (SW) is the smallest, regardless of overall size of the stemmed points.

Panel B of [Figure 7](#fig-plot-cv-all-attributes) shows that CV values for all attributes are distributed from 23.9 to 36.4. Compared to the CVs of Great Basin projectile points (Eerkens and Bettinger, 2001), the average CV for the Korean artifacts is higher. Unlike the distribution of the linear measurements, the CVs of body length and maximum length have the lowest values. The lower CV of maximum length indicates they are highly standardized with narrowest confidence intervals. Tang and stem related attributes (e.g. SL, SW, TL, TW) are less standardized with higher CV values and wider confidence intervals than other attributes. Overall, our results suggests that transmission of stemmed points could be more influenced by guided variation.

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| Figure 7: A. Boxplot for each attribute measured on the stemmed points. The black bold horizontal lines in the middle of boxes represent the median value. The dots represent individual artifacts. B. The points and blue colored numbers represent CV values for each attribute measured on the stemmed points. 95% confidence intervals for the CVs were computed using Sharma and Krishna’s method. The vertical lines indicate the confidence intervals. |

Similar to Panel D of [Figure 4](#fig-corr-analysis), we divided the stemmed points into three chronological phases and computed CV to examine temporal patterns in the modes of cultural transmission. Again, we excluded stemmed points for Phase 1 due to the limited number of artifacts.

[Figure 8](#fig-plot-cv-over-time) shows that the directional trend in CV values of artifact attributes is complicated. Half of the attributes are below our threshold value of 25, and half are above. Only body length crosses the threshold value, changing from <25 to >25 over time, indicating a shift from indirect bias to guided variation. For those attributes where the CV is <25, the trend is decreasing CV values from Phase 2 to Phase 3 for maximum width and tang length, indicating increasing influence of indirect bias for these attributes. For stem length, stem width and tang length, CV values remain above 25, and show a slight trend to increase over time, suggesting increased influence of guided variation for these attributes.

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| Figure 8: CV values for the second and third chronological phases in the Korean Late Paleolithic period. The points represent CV values for each attribute. The vertical lines indicate the confidence intervals. |

Following the previous studies of (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and Bettinger, 2008; Garvey, 2018; Mesoudi and O’Brien, 2008), we only compared CV values of attributes, body length, maximum length, mid width, and tang width for the assemblages that have more than five stemmed points. [Figure 9](#fig-plot-cv-four-assemblage) shows that CV values for the four assemblages are mostly slightly below 25. Among the assemblages, SYG1\_2 has higher CV values as well as the widest ranges of confidence intervals. It is interesting because SYG1\_2 has the strong correlation between attributes ([Figure 5](#fig-plot-cor-four-assemblage)). Perhaps it could be related to its small sample size, relative to the other assemblages compared here. Overall we see only subtle changes in CV values from Phase 2 to Phase 3 in [Figure 9](#fig-plot-cv-four-assemblage). This suggests that the complex directional trends in [Figure 8](#fig-plot-cv-over-time) might be best interpreted as noise in an overall signal of guided variation, rather than substantial changes in the type of bias dominating cultural transmission.

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| Figure 9: CV values of four attributes from assemblages with more than 5 stemmed points. Among the four assemblages, SYG1\_2 and SYG6\_2 are from Phase 2 of the Korean Late Paleolithic chronology and SYG1\_3 and YS\_3 are from Phase 3. The points represent CV values for each attribute. The vertical lines indicate the confidence interval. |

## Variation Between Raw Materials

We examined the relationship between CV values and raw materials to test the hypothesis that the shape of stemmed points was highly dependent on raw material. We excluded raw materials that were used for less than three points. [Figure 10](#fig-plot-cv-by-raw-material) shows that quartzite, the raw material for the stemmed points at Sachang, has the highest CV values, and also has wide conference intervals. Other raw materials are generally stable in variation throughout the attributes.

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| Figure 10: CV values for raw materials that were used for making more than one stemmed point. The points represent CV values for each attribute. The vertical lines indicate the confidence intervals. |

# Discussion

To investigate the social contexts of technological transitions represented by the emergence of stemmed points during the Korean Late Paleolithic, we applied concepts of cultural transmission. We asked three questions to examine the dominant mode of cultural transmission and the transmission process over time: what is the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Do the modes of cultural transmission vary over time? and Do the modes of cultural transmission vary over space? We focused on two transmission biases: guided variation (socially isolated groups made stemmed points through trial and error) and indirect bias (socially connected groups whose knowledge of stemmed points derived from copying others). Following Bettinger and Eerkens (1999), we used 0.5 as a threshold of correlation coefficients to evaluate the two transmission biases. Correlation coefficients below 0.5 are indicative of guided variation and higher values indicate indirect bias. Since there is no clear criteria for CV, we set roughly 25 as our threshold of the CV value to decide between these two types of transmission biases, based on prior work on Great Basin Projectiles (Eerkens and Bettinger, 2001). If the CV value is lower than 25, we interpreted this as indicating indirect bias while values higher than 25 were interpreted as guided variation.

Our correlation analyses show that the correlation coefficients of stemmed points are all positive but mostly under 0.5, showing the possibility of guided variation as their main transmission bias. Some correlations such as body length and maximum length have strong relationship while other correlations such as tang length and body length are much weaker. The correlation coefficients increase from chronological Phases 2 to 3 (Panel D of [Figure 4](#fig-corr-analysis)), but there is no clear pattern and the values vary depending on assemblages ([Figure 5](#fig-plot-cor-four-assemblage)). The CV values for all stemmed point attributes are mostly over 25, except for maximum length, which is just below. Change in CV values for over time in the Korean Late Paleolithic period is complex, with no clear directional changes ([Figure 8](#fig-plot-cv-over-time)). Comparing chronological phases 2 and 3, we found that there are only minor differences between the two phases. Applying the Modified Signed-Likelihood Ratio Test (MSLR) to test for the equality of CVs (Krishnamoorthy and Lee, 2014; Smallwood et al., 2022), we found no statistically significant changes in the CV values of any attributes ([Table 4](#tbl-cv-over-time)) between the two phases. In exploring individual assemblages that contain multiple stemmed points we found confirmation of minimal change in CV values over time ([Figure 9](#fig-plot-cv-four-assemblage)).

Table 4: Summary of significance tests for CV values between the two chronological phases

| Variable | MSLR statistic | p value |
| --- | --- | --- |
| TL | -0.008 | 1.000 |
| SW | 0.019 | 0.890 |
| BL | 0.353 | 0.552 |
| ML | 0.419 | 0.517 |
| SL | 0.471 | 0.493 |
| TW | 0.726 | 0.394 |
| MW | 0.777 | 0.378 |

In exploring geographical variation we found no clear pattern variation in both correlation coefficients ([Figure 5](#fig-plot-cor-four-assemblage)) and CV values ([Figure 9](#fig-plot-cv-four-assemblage)) between assemblages with more than five stemmed points. We found that each assemblage has different distribution patterns of correlation coefficients and CV values. SYG1\_2 and SYG1\_3 are from the same site but different chronological periods and correlations decreases over time. It is likely that correlation or overall shape can be more depending on individual knappers. We also found that some attributes such as maximum width and maximum length have stronger correlation while the others including stemmed length and body length have lower or even negative correlation. We assume that certain attributes were more carefully transmitted than others. We observed that CV values of body length, maximum length, mid width, and tang width are generally lower than tang length, stem length, and stem width, similar to what is evident in [Figure 7](#fig-plot-cv-all-attributes). The attributes with lower CV values could be transmitted in a social context dominated by indirect bias, while the higher CV attributes could be influenced more by specific manufacturing and maintenance situations. We assume that the lower CV values of the four attributes could imply that those four attributes are closely associated with the projectile function of the tool so that the knappers wanted to standardize the shape. For example, body length is related to penetration, durability, hardness, and rejuvenation of a projectile point and tang width is connected to wound damage, penetration, durability and hardness (Bebber et al., 2017; Cheshier and Kelly, 2006; Odell and Cowan, 1986; Shea et al., 2001; Wood and Fitzhugh, 2018; Yaroshevich et al., 2016). This can be contrasted with tang length, stem length, and stem width, which are away from the impact end of the artifact. These were allowed to vary more freely between points, perhaps to be able to accommodate shafts of different types of wood with varying properties of strength, flexibility, and weight.

The most striking differences in both correlation coefficients and CV values is in comparisons of points grouped by raw materials ([Figure 6](#fig-corr-raw-ass), [Figure 10](#fig-plot-cv-by-raw-material)). All distributions are different and there is no clear pattern, indicating that raw materials strongly influence stemmed points. We expected that stemmed points with higher correlation coefficients would have lower CV values, but the actual results do not match our expectations. For example, artifacts made from acidic quartzite have highest correlation but their CV values are also much higher with wider confidence intervals, than all other raw materials. This conflicting results might be related to the relatively unpredictable knapping quality of quartzite. These grains can redirect knapping forces in unexpected directions, resulting in unintended flake removals. This makes is harder for the knapper to repeatedly produce the same size and shape end product. This hints at the possibility that physical properties of the stone artifact raw materials were a key mechanism in determining shape and size variability. However with only three artifacts made from quartzite in our sample, further analysis is needed to make robust conclusions about the influence of raw materials here.

# Conclusion

In this research, we investigated the social context of technological innovation in the Korean Late Paleolithic. Following previous studies of applying cultural transmission to the introduction of bow and arrow technology in the Great Basin (Bettinger and Eerkens, 1999; Bettinger and Eerkens, 1997; Eerkens and Bettinger, 2008; Garvey, 2018), we investigated two transmission biases, guided variation (trial and error) and indirect bias (copying a model). We proposed two scenarios for explaining the introduction of new technology: socially isolated groups that made stemmed points through trial and error (guided variation) or socially connected groups whose knowledge of stemmed points derived from copying others that they regularly came in contact with (indirect bias). We asked three questions: what is the dominant mode of cultural transmission for technological innovation in the Korean Late Paleolithic? Do the modes of cultural transmission vary over time? And do the modes of cultural transmission vary over space?

We conclude that the dominant mode of cultural transmission for the earliest stemmed points was guided variation (trial and error). This is indicated by mostly low correlation coefficients of less than 0.5 and relatively high CV values of around and above 25. A social context that favored trial and error for artifact making is consistent with Seong’s *in situ* model for the appearance of stemmed points in Korea. This model proposes that people developed stemmed points by experimenting with existing blade technologies. Our results support experimentation and trial and error as important processes in the cultural transmission of this artifact technology.

The correlation coefficients suggest a change in the dominant bias of cultural transmission over time, with values around 0.5 in chronological phase 3, after 25 ka. This is in the same range of correlation coefficients that Bettinger and Eerkens interpreted as indirect bias. We also confirm a slight decrease in CV values in four attributes. This results may suggest a shift in the social context of transmission of tool-making skills away from trial and error and towards increased reliance on copying a model. We might speculate based on the evolutionary ecological assumption that cooler conditions of the Last Glacial Maximum promoted greater integration of social networks to buffer risks of resource failure (Fitzhugh, 2001). With more frequent contacts and connections with members of the social network, there may have been more opportunities to learn point-making directly from socially successful individuals.

In comparing assemblages with more than five stemmed points, we found complex variation in CV values that may suggest mixtures of biases in the transmission of tool-making techniques. We did not find strong support for distinctive forms of cultural transmission of tool-making at different assemblages. Correlation coefficient values across the assemblages affirm the overall chronological trend indicating indirect bias in phase three. Raw materials appear to be important in driving this trend, with acid volcanic rocks and porphyry becoming more abundant in phase 3, and dominating assemblages at Yonsangdong that date to this period. One possibility is that these raw materials were part of an adaptive shift during the Last Glacial Maximum, perhaps the cooler climate favored an expanded range for searching for raw materials, leading to a higher diversity. Similarly, change in occupation and mobility patterns may have resulted in more frequent contacts and connections with members of social networks (Park and Marwick, 2022). This may have provided more opportunities to learn point-making directly from socially successful individuals, and increased the contribution of indirect bias during cultural transmission during phase 3.

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# CRediT authorship contribution statement

Gayoung Park: Conceptualization, Software, Validation, Formal analysis, Methodology, Resources, Data curation, Writing - original draft, Writing - Review & Editing, Visualization, Project administration.

Ben Marwick: Software, Validation, Formal analysis, Investigation, Writing - Review & Editing, Visualization, Supervision

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### Colophon

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 P googledrive 2.0.0 2021-07-08 [?] CRAN (R 4.2.0)  
 P googlesheets4 1.0.1 2022-08-13 [?] CRAN (R 4.2.0)  
 P gtable 0.3.1 2022-09-01 [?] CRAN (R 4.2.0)  
 P haven 2.5.1 2022-08-22 [?] CRAN (R 4.2.0)  
 P here 1.0.1 2020-12-13 [?] CRAN (R 4.2.0)  
 P hms 1.1.2 2022-08-19 [?] CRAN (R 4.2.0)  
 htmltools 0.5.4 2022-12-07 [1] CRAN (R 4.2.0)  
 htmlwidgets 1.6.1 2023-01-07 [1] CRAN (R 4.2.0)  
 httpuv 1.6.8 2023-01-12 [1] CRAN (R 4.2.0)  
 P httr 1.4.4 2022-08-17 [?] CRAN (R 4.2.0)  
 jpeg 0.1-10 2022-11-29 [1] CRAN (R 4.2.0)  
 jsonlite 1.8.4 2022-12-06 [1] CRAN (R 4.2.0)  
 knitr 1.42 2023-01-25 [1] CRAN (R 4.2.0)  
 P labeling 0.4.2 2020-10-20 [?] CRAN (R 4.2.0)  
 P later 1.3.0 2021-08-18 [?] CRAN (R 4.2.0)  
 P lattice 0.20-45 2021-09-22 [3] CRAN (R 4.2.2)  
 P legendMap \* 1.0 2023-02-13 [?] Github (3wen/legendMap@707f00c)  
 P lifecycle 1.0.3 2022-10-07 [?] CRAN (R 4.2.0)  
 limma 3.54.1 2023-01-26 [1] Bioconductor  
 lubridate 1.9.2 2023-02-10 [1] CRAN (R 4.2.0)  
 P magrittr \* 2.0.3 2022-03-30 [?] CRAN (R 4.2.0)  
 P maps \* 3.4.1 2022-10-30 [?] CRAN (R 4.2.0)  
 maptools \* 1.1-6 2022-12-14 [1] CRAN (R 4.2.0)  
 P memoise 2.0.1 2021-11-26 [?] CRAN (R 4.2.0)  
 P mime 0.12 2021-09-28 [?] CRAN (R 4.2.0)  
 P miniUI 0.1.1.1 2018-05-18 [?] CRAN (R 4.2.0)  
 P MKmisc \* 1.9 2022-11-19 [?] CRAN (R 4.2.0)  
 P modelr 0.1.10 2022-11-11 [?] CRAN (R 4.2.0)  
 P munsell 0.5.0 2018-06-12 [?] CRAN (R 4.2.0)  
 P pillar 1.8.1 2022-08-19 [?] CRAN (R 4.2.0)  
 P pkgbuild 1.4.0 2022-11-27 [?] CRAN (R 4.2.0)  
 P pkgconfig 2.0.3 2019-09-22 [?] CRAN (R 4.2.0)  
 P pkgload 1.3.2 2022-11-16 [?] CRAN (R 4.2.0)  
 P plyr 1.8.8 2022-11-11 [?] CRAN (R 4.2.0)  
 png 0.1-8 2022-11-29 [1] CRAN (R 4.2.0)  
 P prettyunits 1.1.1 2020-01-24 [?] CRAN (R 4.2.0)  
 P processx 3.8.0 2022-10-26 [?] CRAN (R 4.2.0)  
 P profvis 0.3.7 2020-11-02 [?] CRAN (R 4.2.0)  
 P promises 1.2.0.1 2021-02-11 [?] CRAN (R 4.2.0)  
 P ps 1.7.2 2022-10-26 [?] CRAN (R 4.2.0)  
 purrr \* 1.0.1 2023-01-10 [1] CRAN (R 4.2.0)  
 P R6 2.5.1 2021-08-19 [?] CRAN (R 4.2.0)  
 P raster \* 3.6-14 2023-01-16 [?] CRAN (R 4.2.0)  
 P RColorBrewer \* 1.1-3 2022-04-03 [?] CRAN (R 4.2.0)  
 Rcpp 1.0.10 2023-01-22 [1] CRAN (R 4.2.0)  
 readr \* 2.1.4 2023-02-10 [1] CRAN (R 4.2.0)  
 readxl 1.4.2 2023-02-09 [1] CRAN (R 4.2.0)  
 P remotes 2.4.2 2021-11-30 [?] CRAN (R 4.2.0)  
 P reprex 2.0.2 2022-08-17 [?] CRAN (R 4.2.0)  
 P rgeos 0.6-1 2022-12-14 [?] CRAN (R 4.2.0)  
 P RgoogleMaps 1.4.5.3 2020-02-12 [?] CRAN (R 4.2.0)  
 P rlang 1.0.6 2022-09-24 [?] CRAN (R 4.2.0)  
 rmarkdown 2.20 2023-01-19 [1] CRAN (R 4.2.0)  
 P robustbase 0.95-0 2022-04-02 [?] CRAN (R 4.2.0)  
 P rprojroot 2.0.3 2022-04-02 [?] CRAN (R 4.2.0)  
 P rstudioapi 0.14 2022-08-22 [?] CRAN (R 4.2.0)  
 P rvest 1.0.3 2022-08-19 [?] CRAN (R 4.2.0)  
 P scales 1.2.1 2022-08-20 [?] CRAN (R 4.2.0)  
 P sessioninfo 1.2.2 2021-12-06 [?] CRAN (R 4.2.0)  
 shiny 1.7.4 2022-12-15 [1] CRAN (R 4.2.0)  
 sp \* 1.6-0 2023-01-19 [1] CRAN (R 4.2.0)  
 stringi 1.7.12 2023-01-11 [1] CRAN (R 4.2.0)  
 stringr \* 1.5.0 2022-12-02 [1] CRAN (R 4.2.0)  
 P terra 1.7-3 2023-01-24 [?] CRAN (R 4.2.0)  
 P tibble \* 3.1.8 2022-07-22 [?] CRAN (R 4.2.0)  
 tidyr \* 1.3.0 2023-01-24 [1] CRAN (R 4.2.0)  
 P tidyselect 1.2.0 2022-10-10 [?] CRAN (R 4.2.0)  
 P tidyverse \* 1.3.2 2022-07-18 [?] CRAN (R 4.2.0)  
 timechange 0.2.0 2023-01-11 [1] CRAN (R 4.2.0)  
 P tzdb 0.3.0 2022-03-28 [?] CRAN (R 4.2.0)  
 P urlchecker 1.0.1 2021-11-30 [?] CRAN (R 4.2.0)  
 P usethis 2.1.6 2022-05-25 [?] CRAN (R 4.2.0)  
 utf8 1.2.3 2023-01-31 [1] CRAN (R 4.2.0)  
 vctrs 0.5.2 2023-01-23 [1] CRAN (R 4.2.0)  
 P vipor 0.4.5 2017-03-22 [?] CRAN (R 4.2.0)  
 vroom 1.6.1 2023-01-22 [1] CRAN (R 4.2.0)  
 P withr 2.5.0 2022-03-03 [?] CRAN (R 4.2.0)  
 xfun 0.37 2023-01-31 [1] CRAN (R 4.2.0)  
 P xml2 1.3.3 2021-11-30 [?] CRAN (R 4.2.0)  
 P xtable 1.8-4 2019-04-21 [?] CRAN (R 4.2.0)  
 yaml 2.3.7 2023-01-23 [1] CRAN (R 4.2.0)  
  
 [1] /Users/bmarwick/Library/Caches/org.R-project.R/R/renv/library/CTtps-93b8de19/R-4.2/x86\_64-apple-darwin17.0  
 [2] /Users/bmarwick/Downloads/CTtps/renv/sandbox/R-4.2/x86\_64-apple-darwin17.0/84ba8b13  
 [3] /Library/Frameworks/R.framework/Versions/4.2/Resources/library  
  
 P ── Loaded and on-disk path mismatch.  
  
──────────────────────────────────────────────────────────────────────────────

The current Git commit details are:

Local: master /Users/bmarwick/Downloads/CTtps  
Remote: master @ origin (https://github.com/parkgayoung/CTtps)  
Head: [53e6fd3] 2023-02-10: finish editing conclusion