Cultural Transmission and Technological Transitions during the Late Paleolithic in Korea

Gayoung Park1,✉, and Ben Marwick1

October 16, 2022

Archaeologists have applied evolutionary concepts linking material evidence and cultural phenomena to understand human behavior. Evolutionary approaches suggest that technological transitions can occur through changes in social learning processes, and transmission biases are important loci of changes. The onset of the Late Paleolithic period in Korea, represented by the appearance of stemmed points and blades, is a key event in understanding modern human dispersal in Northeast Asia. Previous studies mainly focus on possible origin locations of new technologies, but they rarely address the process of the technological transition. In this research we use a cultural transmission framework to investigate the social contexts that can give us insights into the emergence of these new technologies. Our main question is: what was the dominant mode of cultural transmission during the time of technological innovation in the Korean Late Paleolithic? Inspired by Bettinger and Eerkens (1999), we build two models using guided variation and indirect bias. To test the models and understand the transmission processes, we use coefficients of variation (CV), and Principal Component Analysis (PCA). Here we show that the information about the new technology was transmitted via selective combinations of guided variation and indirect bias. We found that some attributes including length and width were transmitted through indirect bias, while other attributes appear to have been more dependent on raw materials or other factors.

1 Department of Anthropology, University of Washington

✉ Correspondence: [Gayoung Park <gayoungp@uw.edu>](mailto:gayoungp@uw.edu)

# Introduction

The application of evolutionary theory to archaeological research has guided the interpretation of technological transitions and related human behaviors (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). We use cultural transmission theory to investigate technological transitions during the Korean Late Paleolithic. This technological innovation is not just the appearance of new tools such as stemmed points and blades, but may also represent a key event related to modern human dispersal in East Asia, if the appearance of these new technologies represents the first arrival of modern humans in this region (Seong, 2009). Previous studies mainly focused on the possible origin locations of stemmed points, to connect Korea with global patterns of modern human dispersal. Questions about the processes of technological change 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 is 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? Do the modes of cultural transmission vary over space? We consider three possibilities, guided variation (trial and error), or indirect bias (copying others), or a combination of the two. Our results can help to determine 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 is the first composite tool type and represents new hunting strategies in the Korean Peninsula, as well as other adjacent regions (Lee and Sano, 2019; Seong, 2008). Stemmed points, combined with blade technology and multi-stage production sequences, and evidence of being resharpened and reused, are important aspects of Late Paleolithic technological innovation 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 technological transitions during the Late Paleolithic in Korea mainly focused on possible origin locations of stemmed points, along with the issue 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 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 idea of gradual, local, evolutionary process.

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 (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 was 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 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 in 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 those 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

Darwinian evolutionary theory has helped archaeologists understand technological innovation 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 can explain cultural changes using mechanisms of inheritance, variation-generating processes, and selection. The mechanisms are similar to biological evolution, but unique to cultural systems. We focus here on how different social contexts result in different modes of social transmission of tool-making skills. Social transmission can occur through various learning processes, such as stimulus enhancement, emulation, imitation, and teaching (O’brien and Lyman, 2000; Schillinger et al., 2014).

Cultural transmission theory holds that information about how to behave 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 through 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 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 and then modify them 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 instructions based on their perceived frequency in the population, such as extremely popular or rare instructions), and indirect bias (where a variant 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 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 with high metric variation and low correlation between metric attributes. Conversely, they inferred indirect bias 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, with new technologies developed largely by trial and error. On the other hand, in central Nevada metric variables are highly correlated, indicating that the bow and arrow was introduced and spread by indirect bias.

Garvey (2018) also explores Bettinger and Eerkens’ framework and uses simulation to explore the degree of standardization represented by coefficient of variation (CV) values of projectile points. With the two types of projectile points, Washita and Fresno points, from Henderson site, she measured CV values of weight, thickness, width and lengths. She then computed simulated CV values according to various learning scenarios of knapper skill, raw material quality and human perception (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”. Garvey’s modeling and simulation show how the concept of cultural transmission can be useful to interpret the archaeological record.

Although Garvey and Bettinger and Eerkens were unable to directly observe transmission processes, Mesoudi and O’Brien (2008) 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 results demonstrate the robustness of previous assumptions about cultural transmission biases and their consequences for variation and correlation in material culture.

# Modeling the social context of the appearance of stemmed points

Inspired by the previous studies that used Bettinger and Eerkens’ approach, we use the two contrasting transmission modes, guided variation and indirect bias, to understand the spread of stemmed point technology during the Korean Late Paleolithic period. We propose a spectrum for foraging groups and how they started to make stemmed points: on one end we have socially isolated groups who made stemmed points entirely stimulated by guided variation; and on the other end of the spectrum we have socially connected groups whose knowledge of stemmed points derived from indirect bias on the transmission process.

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. This trial and error behavior leaves a distinctive signature on metric variables of the stemmed points. If trial and error was the dominant bias in the appearance of stemmed points, we expect that the morphological attributes on a stemmed point will be poorly correlated and show high variation between sites.

On the other end of our spectrum, socially connected groups occupied places close to other groups or had regular contact with other groups over long or short distances. Individuals or groups learned the technology of stemmed points by copying a model from another individual or group. The model stemmed point might be a highly successful and frequently chosen one, and the learners copy all information about the point design as a package. 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 be less varied.

# Materials and methods

## Materials and stemmed points chronology

After the first discovery in Seokjangri site in the 1960s, around 300 stemmed points 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 28 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.

We used previously developed chronologies that identify three phases in the Korean Late Paleolithic (Park, 2013; Seong, 2015). These chronologies were built on the presence of blades, stemmed point blanks, toolkit composition and radiocarbon ages. We arranged our 28 assemblages containing stemmed points in chronological order. For example, Sachang site has two assemblages that are fitted into phase 1 and 2. Applying the chronology is useful because some sites such as Yonghodong, Goryeri, Jungmal, and Mungyeong have no radiocarbon dates due to various research situations and limitations, chronological order help us estimate the time periods of those assemblages as well as understand the morphological change of stemmed points associated with the introduction of blade technology. Based on the existence of blade and micro blade and types of stemmed point blanks, we divided the assemblages into three chronological phases: 1) stemmed points made out of flakes and no blades in assemblages, 2) stemmed points made out of blade or flake and the existence of blade in assemblages, and 3) stemmed points made out of blade and the existence of micro blade in assemblages ([Table 2](#tbl-korean-chronology)).

|  |
| --- |
| 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 | X..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 |

Table 2: Korean Paleolithic Chronology edited based on Seong (2015) and Park (2013)

| 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 |

## Methods

In addition to the metric attributes from 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 additional morphological attributes on the stemmed points to examine variations in shape and the relationship between each attribute ([Figure 2](#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 (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 were: (1) the tip of the point; (2) the left side of mid-point; (3) the left wing, which can be overlapped with the mid-point; (4) the left side of the mid-point on the tang curve; (5) the left side of 5mm above the basal end; (6) the center of the basal end; (7) the tip of the basal end, which can be overlapped with the center of the basal end ; (8) the right side of 5mm above the basal end ; (9) the right side of the mid-point on the tang curve; (10) the right wing; and (11) the right side of mid-pint, which can be overlapped with the right wing. We used the point tool in ImageJ (Schneider et al., 2012) to capture the landmarks and export them as XY coordinate data ([Table 3](#tbl-landmark-abbreviations)).

|  |
| --- |
| Figure 2: Stemmed point from Yongsandong site. with landmarks showing the attributes considered in this study and corresponding landmarks |

Table 3: Description of artefact 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 |

To measure the variations between stemmed points, we used Coefficients of Variation (CV) with confidence intervals. CV is the ratio 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). In archaeological studies, CV has been applied to measure the variation between artifacts and test hypotheses about cultural evolutionary processes including distinguishing different types of learning biases affecting cultural transmission (Eerkens and Bettinger, 2001; Eerkens and Lipo, 2005; Garvey, 2018; Schillinger et al., 2014). Eerkens and Bettinger (2001) summarize CV values for artifacts made from various materials and find that the range of CV values for most archaeological datasets is between 2% (i.e. CV for planned production = 1.7 %) and about 60% (i.e. CV for random production = 57.7%) and the values over the upper limit likely reflect intended attempts to differentiate the products. Among the Great Basin Projectiles examined by Eerkens and Bettinger, the average CV was 22 and the range in CV values was 6-55. Considering the lower quality of raw materials in Korea, we sat roughly 25 as the threshold to decide the type of transmission biases.

Sample size can impact on accuracy of estimated CV that reflects the corresponding population size. (Kelley, 2007; Toebe et al., 2018; VanPool and Leonard, 2011). In previous archaeological studies, sample sizes for CV values varies from 5 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 on small samples. VanPool and Leonard (2011) proposed a “corrected CV”, for a smaller sample (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). Since our sample size is 152 artifacts, we used the standard CV formula rather than that of VanPool and Leonard (2011), and we computed confidence intervals using the Sharma and Krishna model to increase the credibility of the comparisons and be transparent about the precision and accuracy of our results. (Albatineh et al., 2014; Kelley, 2007).

We chose Principal Component Analysis (PCA) to compute Pearson’s r correlations between the attributes as previous studies did (Bettinger and Eerkens, 1999; Eerkens and Bettinger, 2008; Garvey, 2018) and to investigate the relationship between attributes as well as the impact of each attribute on the overall shape of stemmed points. PCA is often used to detect relevant information from dataset, indicate relationships between variables as well as cases, extract general patterns in data, and identify which variables most influence these patterns (Cascalheira and Bicho, 2018; Suárez and Cardillo, 2019). PCA is widely used for geometric morphometric analysis of artifacts to extract general patterns of shape variation (Ivanovaitė et al., 2020; Leplongeon et al., 2020; Selden et al., 2014; Suárez and Cardillo, 2019).

All data treatment, analyses and visualization were performed in the R environment (Core, 2021). Our R code and data including the raw images are openly available online: https://github.com/parkgayoung/CTtps as well as https://doi.org/10.17605/osf.io/eb8mx to enable full reproducibility (Marwick, 2017).

# Results

## Distribution of attributes

[Figure 3](#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 and most highly standardized, regardless of overall size of the stemmed points. This result implies a similar thickness of a wooden shaft that is attached to the stem.

## Coefficient of variation

We used CV to measure the variations between stemmed points. If the variation is high, the transmission might happen through guided variation while the low variation represents indirect bias. Our results show that CV values for all attributes are distributed from 23.8 to 36.3 ([Figure 3](#fig-plot-cv-all-attributes)). Compared to the CVs of Great Basin projectile points (Eerkens and Bettinger, 2001), the average CV is higher. Unlike the distribution of actual attributes ([Figure 3](#fig-plot-cv-all-attributes) panel A), 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 Among all the attributes, only maximum length has the CV values lower than 25, which could be the result of indirect bias.

|  |
| --- |
| Figure 3: 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 artefacts. 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 range of confidence intervals. |

## Variation Over Time

To understand the temporal patterns in the modes of cultural transmission, we applied Korea Late Paleolithic chronological phases into our samples to compute CV ([Table 2](#tbl-korean-chronology)). Among the three phases of the chronology, we excluded Phase 1 for the analysis because there are only two stemmed points from Yonghodong and Sachang sites to compute. However, this does not mean that there were only two stemmed points for the Phase 1 because we excluded broken pieces from our sample to conduct the morphological analysis.

After excluding the Phase 1 stemmed points, overall CV values become lower ([Figure 4](#fig-plot-cv-over-time)). Body length of Phase 2, maximum length, mid width, and tang width are under 25, which indicates as a result of indirect bias, while only maximum length are under 25 in Figure 4. On the other hand, Body length of Phase 3, stem length, stem width, and tang length are relatively higher then 25 and mostly over 30 indicating guided variation.

Compared to Phase 2, except for maximum width and tang width, the other CV values of Phase 3 tend to be higher. In addition, Phase 3 tends to have wider confidence intervals. Stem width and tang length values are relatively steady over time. Our results show that stemmed points from Phase 2 are less varied than Phase 3 as well as Phase 1.

|  |
| --- |
| Figure 4: 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 range of confidence intervals. |

We then explored assemblages that contain multiple stemmed points to examine the temporal patterns with the premise that stemmed points from one assemblage were made by the same group of people. There are four assemblages, three assemblages from the Suyanggae site (SYG) and one from the Yongsandong site (YS) that contain more than 5 stemmed points. SYG1\_2 and SYG6\_2 are from Phase 2 and SYG1\_3 and YS\_3 are from Phase 3. 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. [Figure 5](#fig-plot-cv-four-assemblage) shows that CV values for the four assemblages are mostly below 25, which represent transmissions through indirect bias. Among the assemblages, SYG1\_2 (n=7) has higher CV values as well as the widest range of confidence intervals. Compared to the Phase 2, CV values of Phase 3 are lower, which is different from [Figure 4](#fig-plot-cv-over-time) results of body length and maximum length from all assemblages. It is assumed that those attributes became more standardized within the same assemblages. Compared to Suyanggae assemblages, Yongsandong has smaller CV values.

|  |
| --- |
| Figure 5: CV values of four attributes from assemblages that 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. |

## Variation Between sites

We examined the CV values per site to address our research question about the cultural transmission over space. We excluded assemblages that contain a single point. [Figure 6](#fig-plot-cv-by-site) shows that Sachang site has the highest CV values with the widest confidence level. Sachang is part of Phase 1 and its CV values explain why the CV of all time is higher than Phase 2. Two assemblages from the Suyanggae site have relatively stable CV for attributes, which indicate highly standardized shapes of stemmed points. CV values of body length is the lowest while stem width the highest among all assemblages. Overall, there are no clear patterns between the sites.

|  |
| --- |
| Figure 6: CV values per site that has more than one stemmed point. The points represent CV values for each attribute. The vertical lines indicate the range of confidence intervals. |

## Variation Between Raw Materials

We examined the relationship between CV values and raw materials with a premise that the shape of stemmed points are highly dependent on raw materials. We excluded raw materials that were used for single point. [Figure 7](#fig-plot-cv-by-raw-material) shows that quartzite, the raw materials for Sachang stemmed points, has the highest CV value with a wide range of conference intervals. Quartz has high variations of CV among the attributes. On the other hand, shale has the lower CV, which is very stable throughout the attributes.

|  |
| --- |
| Figure 7: 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 range of confidence intervals. |

## Principal Component Analysis

PCA serves to examine correlation of attributes for determining the dominant mode of cultural transmission. [Figure 8](#fig-pca-attributes) shows positive relationship between attributes. Especially, there are strong relationships between body length and maximum length, tang width and mid width, and tang length and stem length. Body length and maximum length contribute the most to the shape of stemmed points and they are most correlated to each other. Other width and tang related attributes are close to each other but a bit far from body length and maximum length. Stem width contributes the least to the overall shape. We can assume that the body length and maximum length were prioritized when the manufacturing technique of stemmed points were transmitted.

For the temporal variation, we computed PCA for difference periods. Compared to Phase 2, the influence of tang length and stem length of Phase 3 becomes more pronounced and while stem width is less effective. However, there are no notable changes in correlations over time.

|  |
| --- |
| Figure 8: PCA analysis for stemmed points, for all phases combined, then for only phase two and phase three. The direction of the arrow shows the relationship between attributes; arrows pointing in the same direction indicate variables that are highly postitively correlated. The length of the arrow indicates the strength of contribution to the stemmed point shape. |

# 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). We set 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) and the relatively lower quality of lithic raw materials in Korea. If the CV value is lower than 25, which indicates indirect bias while the value is 25 or higher means guided variation.

The CV values for all stemmed points are mostly over 25, except for maximum length which is 23.8. PCA analysis shows positive relationships between attributes. We then examined the CV values for chronological phases in the Korean Late Paleolithic period ([Figure 4](#fig-plot-cv-over-time)). After excluding two stemmed points for the Phase 1 to compute CV due to the small sample size issue, the overall CV values become lower. In addition to the maximum length, body length, mid width, and tang width for the Phase 2 are under 25. We observe the different degree of contribution by each attribute to the shape of stemmed points. For example, tang and stem related attributes have higher CV values compared to the body related attributes. We expect that people chose to emulate the body related attributes and had more freedom to produce the tang and stem related attributes.

Compared to the Phase 2 and 3, we found that there are only minor differences between the two phases. The CV of the two most important attributes, body length and maximum length, slightly increased in Phase 3. The increase is not significant to generalize (p > 0.05, **?@tbl-cv-over-time**), we explored individual assemblages including multiple stemmed points that could show a more clear pattern. The four assemblages in Suyanggae and Yongsandong sites show that CV values decreased with narrower confidence intervals, which means a high degree of precision ([Figure 5](#fig-plot-cv-four-assemblage)). This could indicate the stronger connections within the groups during Phase 3.

| Variable | MSLR statistic | p value |
| --- | --- | --- |
| ML | 0.4098458 | 0.5220478 |
| BL | 0.3524404 | 0.5527349 |
| TL | 0.0163396 | 0.8982863 |
| SL | 0.4646099 | 0.4954774 |
| MW | 0.8000294 | 0.3710846 |
| TW | 0.7110450 | 0.3990971 |
| SW | 0.0181961 | 0.8926965 |

**?(caption)**

There is no clear pattern variation in CV between the sites. Some sites such as Sachang have very high CV values while other sites including Suyanggae and Jingeunuel have lower CV ([Figure 6](#fig-plot-cv-by-site)). We assumed that the CV could be impacted by other factors such as the choice of raw materials ([Figure 7](#fig-plot-cv-by-raw-material)). However, similar to the CV variation for the Phase 2, the results of site variation show that CV of body length, maximum length, mid width, and tang width are generally lower than tang length, stem length, and stem width, indicating the combination of the two biases. The attributes with lower CV values could be taught through indirect bias while the higher CV attributes could be depending more on various manufacturing situations. We assume that the lower CV values of the four attributes could imply that those four attributes are closely associated with the 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 combination model describes that there were social connections between groups that share the tool production technique. Individuals or groups learned the major technology of stemmed points by copying a model from another individual or group (indirect bias). Then, those individuals or groups adjusted their technique and shape of the stem depending on their needs and material availability. Our results recalls -Lee (2013)’s model but his model explains combination of the *in situ* tradition for flake tools and introduction of blade-associate toolkit including stemmed points. On the other hand, we saw the combination of the *in situ* tradition and introduced stemmed point technology within the single artifact.

# Conclusion

In this research, we examine the dominant mode of cultural transmission that might impact technological innovation in the Korean Late Paleolithic. Following the 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 use two transmission biases, guided variation and indirect bias to scrutinize the transmission process and social contexts. We claim the two scenarios that explains the introduction of new technology: socially isolated groups made stemmed points through trial and error (guided variation) or socially connected groups whose knowledge of stemmed points derived from copying others (indirect bias). We ask 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? To determine transmission biases and answer our research questions, we computed CV and PCA. The higher CV values (i.e. >=25) and low correlation indicate guided variation while the lower CV while the lower CV values (i.e. <25) and high correlations represent indirect bias. To offset the small sample issue and increase the credibility of the comparisons, we applied confidence intervals to CV for better estimation.

Our results show that some attributes such as body length, maximum length, mid width, and tang width were transmitted through indirect bias and the other attributes were developed through guided variation. All attributes are positively related and those low variation attributes are more closely associated and highly contribute to the overall shape of the stemmed points. We assume that the guided variation played a more important role at the beginning of the transition based on high CV values of Phase 1. We observe a slight decrease in CV values over time. No clear regional patterns are confirmed. CV values could be vary depending on raw materials. For example, coarse materials like quartzite have the highest CV values with the widest range of confidence intervals. Overall, we conclude that combination of the two transmission biases well explains the technological transition during the Late Paleolithic. We anticipate that our theoretical approach is applicable to other studies about technological transition and cultural transmission. We used landmarks to earn the dimensional attributes, which has potential for future research with different dimensions by calculating the distance between other sets of the existing landmarks. In our future research, we will focus on understanding actual connection between the assemblages and examining the social networks for sharing technology between the groups such as trades or physical migration to different locations.

# Acknowledgements

# 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

# References

Albatineh, A.N., Kibria, B.G., Wilcox, M.L., Zogheib, B., 2014. Confidence interval estimation for the population coefficient of variation using ranked set sampling: A simulation study. Journal of Applied Statistics 41, 733–751.

Bae, C., Bae, K., Kim, J.C., 2013. The early to late paleolithic transition in korea: A closer look. Radiocarbon 55, 1341–1349.

Bae, C.J., Bae, K., 2012. The nature of the early to late paleolithic transition in korea: Current perspectives. Quaternary International 281, 26–35.

Bae, C.J., Douka, K., Petraglia, M.D., 2017. On the origin of modern humans: Asian perspectives. Science 358, eaai9067.

Bae, K., 2010. Origin and patterns of the upper paleolithic industries in the korean peninsula and movement of modern humans in east asia. Quaternary International 211, 103–112.

Bamforth, D.B., 2009. Projectile points, people, and plains paleoindian perambulations. Journal of Anthropological Archaeology 28, 142–157.

Banik, S., Kibria, B.G., 2011. Estimating the population coefficient of variation by confidence intervals. Communications in Statistics-Simulation and Computation 40, 1236–1261.

Bebber, M.R., Lycett, S.J., Eren, M.I., 2017. Developing a stable point: Evaluating the temporal and geographic consistency of late prehistoric unnotched triangular point functional design in midwestern north america. Journal of Anthropological Archaeology 47, 72–82.

Bettinger, R.L., Eerkens, J., 1999. Point typologies, cultural transmission, and the spread of bow-and-arrow technology in the prehistoric great basin. American antiquity 231–242.

Bettinger, R.L., Eerkens, J., 1997. Evolutionary implications of metrical variation in great basin projectile points. Archeological Papers of the American Anthropological Association 7, 177–191.

Bettinger, R.L., Eerkens, J.W., Barton, C., Clark, G., 1997. Rediscovering darwin: Evolutionary theory and archaeological explanation.

Boyd, R., Richerson, P.J., 1988. Culture and the evolutionary process. University of Chicago press.

Buchanan, B., Collard, M., 2010. A geometric morphometrics-based assessment of blade shape differences among paleoindian projectile point types from western north america. Journal of Archaeological Science 37, 350–359.

Cardillo, M., Borrazzo, K., Charlin, J., 2016. Environment, space, and morphological variation of projectile points in patagonia (southern south america). Quaternary International 422, 44–56.

Cascalheira, J., Bicho, N., 2018. The use of lithic assemblages for the definition of short-term occupations in hunter-gatherer prehistory.

Chang, Y., 2013. Human activity and lithic technology between korea and japan from MIS 3 to MIS 2 in the late paleolithic period. Quaternary International 308, 13–26.

Cheshier, J., Kelly, R.L., 2006. Projectile point shape and durability: The effect of thickness: length. American Antiquity 353–363.

Core, R., 2021. Team. R: A language and environment for statistical computing, 2015.

Costin, C.L., Hagstrum, M.B., 1995. Standardization, labor investment, skill, and the organization of ceramic production in late prehispanic highland peru. American Antiquity 60, 619–639.

Creanza, N., Kolodny, O., Feldman, M.W., 2017. Cultural evolutionary theory: How culture evolves and why it matters. Proceedings of the National Academy of Sciences 114, 7782–7789.

Curto, J.D., Pinto, J.C., 2009. The coefficient of variation asymptotic distribution in the case of non-iid random variables. Journal of Applied Statistics 36, 21–32.

Dunnell, R.C., 1980. Evolutionary theory and archaeology, in: Advances in Archaeological Method and Theory. Elsevier, pp. 35–99.

Eerkens, J.W., Bettinger, R.L., 2008. Cultural transmission and the analysis of stylistic and functional variation. Transmission and Archaeology: Issues and Case-Studies 21–38.

Eerkens, J.W., Bettinger, R.L., 2001. Techniques for assessing standardization in artifact assemblages: Can we scale material variability? American Antiquity 493–504.

Eerkens, J.W., Lipo, C.P., 2007. Cultural transmission theory and the archaeological record: Providing context to understanding variation and temporal changes in material culture. Journal of Archaeological Research 15, 239–274.

Eerkens, J.W., Lipo, C.P., 2005. Cultural transmission, copying errors, and the generation of variation in material culture and the archaeological record. Journal of Anthropological Archaeology 24, 316–334.

Garvey, R., 2018. Current and potential roles of archaeology in the development of cultural evolutionary theory. Philosophical Transactions of the Royal Society B: Biological Sciences 373, 20170057.

Gulhar, M., Kibria, B.G., Albatineh, A.N., Ahmed, N.U., 2012. A comparison of some confidence intervals for estimating the population coefficient of variation: A simulation study. SORT-Statistics and Operations Research Transactions 45–68.

Heyes, C.M., 1994. Social learning in animals: Categories and mechanisms. Biological Reviews 69, 207–231.

Ivanovaitė, L., Serwatka, K., Hoggard, C.S., Sauer, F., Riede, F., 2020. All these fantastic cultures? Research history and regionalization in the late palaeolithic tanged point cultures of eastern europe. European Journal of Archaeology 23, 162–185.

Kelley, K., 2007. Sample size planning for the coefficient of variation from the accuracy in parameter estimation approach. Behavior Research Methods 39, 755–766.

Kendal, R.L., Boogert, N.J., Rendell, L., Laland, K.N., Webster, M., Jones, P.L., 2018. Social learning strategies: Bridge-building between fields. Trends in cognitive sciences 22, 651–665.

Kim, E., 2017. Morphological diversity and functional differentiation of tanged-point: Focused on suyanggae, jingeuneul and yongsandong site. Journal of Korean Paleolithic Society 29–47.

Koopmans, L.H., Owen, D.B., Rosenblatt, J.I., 1964. Confidence intervals for the coefficient of variation for the normal and log normal distributions. Biometrika 51, 25–32.

Kvamme, K.L., Stark, M.T., Longacre, W.A., 1996. Alternative procedures for assessing standardization in ceramic assemblages. American Antiquity 61, 116–126.

Lee, G.-K., Sano, K., 2019. Were tanged points mechanically delivered armatures? Functional and morphometric analyses of tanged points from an upper paleolithic site at jingeuneul, korea. Archaeological and Anthropological Sciences 11, 2453–2465.

Lee, H.W., 2013. Current observations of the early late paleolithic in korea. Quaternary International 316, 45–58.

Leplongeon, A., Ménard, C., Bonhomme, V., Bortolini, E., 2020. Backed pieces and their variability in the later stone age of the horn of africa. African Archaeological Review 37, 437–468.

Lipo, C.P., Madsen, M.E., Dunnell, R.C., Hunt, T., 1997. Population structure, cultural transmission, and frequency seriation. Journal of Anthropological Archaeology 16, 301–333.

Lycett, S.J., 2015. Cultural evolutionary approaches to artifact variation over time and space: Basis, progress, and prospects. Journal of Archaeological Science 56, 21–31.

MacLeod, N., 2018. The quantitative assessment of archaeological artifact groups: Beyond geometric morphometrics. Quaternary Science Reviews 201, 319–348.

Mahmoudvand, R., Hassani, H., 2009. Two new confidence intervals for the coefficient of variation in a normal distribution. Journal of Applied Statistics 36, 429–442.

Marwick, B., 2017. Computational reproducibility in archaeological research: Basic principles and a case study of their implementation. Journal of Archaeological Method and Theory 24, 424–450.

McKay, A., 1932. Distribution of the coefficient of variation and the extended" t" distribution. Journal of the Royal Statistical Society 95, 695–698.

Mesoudi, A., O’Brien, M.J., 2008. The cultural transmission of great basin projectile-point technology i: An experimental simulation. American Antiquity 3–28.

Miller, R., 1991. Asymptomatic test statistics for coefficients of variation. Theor Meth 20, 2251–2262.

Ng, C., 2006. Performance of three methods of interval estimation of the coefficient of variation. InterStat.

O’Brien, M.J., Bentley, R.A., 2017. Dual inheritance, cultural transmission, and niche construction. The Handbook of Culture and Biology.

O’brien, M.J., Lyman, R.L., 2000. Applying evolutionary archaeology: A systematic approach. Springer Science & Business Media.

Odell, G.H., Cowan, F., 1986. Experiments with spears and arrows on animal targets. Journal of Field Archaeology 13, 195–212.

Okumura, M., Araujo, A.G., 2019. Archaeology, biology, and borrowing: A critical examination of geometric morphometrics in archaeology. Journal of Archaeological Science 101, 149–158.

Panichkitkosolkul, W., 2013. Confidence intervals for the coefficient of variation in a normal distribution with a known population mean. Journal of Probability and Statistics 2013.

Panichkitkosolkul, W., 2009. Improved confidence intervals for a coefficient of variation of a normal distribution. Thailand statistician 7, 193–199.

Park, G., 2013. A study on the stemmed points of the late paleolithic in the korean peninsula. Yeongnam Archaeological Review 64, 39–69.

Petřı́k, J., Sosna, D., Prokeš, L., Štefanisko, D., Galeta, P., 2018. Shape matters: Assessing regional variation of bell beaker projectile points in central europe using geometric morphometrics. Archaeological and Anthropological Sciences 10, 893–904.

Richerson, P.J., Boyd, R., 1992. Cultural inheritance and evolutionary ecology. Evolutionary ecology and human behavior 61–92.

Riede, F., 2010. Why isn’t archaeology (more) darwinian? A historical perspective. Journal of Evolutionary Psychology 8, 183–204.

Rivals, F., Schulz, E., Kaiser, T.M., 2009. A new application of dental wear analyses: Estimation of duration of hominid occupations in archaeological localities. Journal of Human Evolution 56, 329–339.

Schillinger, K., Mesoudi, A., Lycett, S.J., 2014. Copying error and the cultural evolution of" additive" vs." Reductive" material traditions: An experimental assessment. American Antiquity 128–143.

Schneider, C.A., Rasband, W.S., Eliceiri, K.W., 2012. NIH image to ImageJ: 25 years of image analysis. Nature methods 9, 671–675.

Selden, R.Z., Perttula, T.K., O’Brien, M.J., 2014. Advances in documentation, digital curation, virtual exhibition, and a test of 3D geometric morphometrics: A case study of the vanderpool vessels from the ancestral caddo territory. Advances in Archaeological Practice 2, 64–79.

Seong, C., 2015. Diversity of lithic assemblages and evolution of late palaeolithic culture in korea. Asian Perspectives 91–112.

Seong, C., 2009. Emergence of a blade industry and evolution of late paleolithic technology in the republic of korea. Journal of Anthropological Research 65, 417–451.

Seong, C., 2008. Tanged points, microblades and late palaeolithic hunting in korea. Antiquity 82, 871–883.

Seong, C., 2006. Structure and evolution of late paleolithic assemblages in korea. Journal of the Korean Archaeological Society 59, 4–39.

Sharma, K., Krishna, H., 1994. Asymptotic sampling distribution of inverse coefficient-of-variation and its applications. IEEE Transactions on Reliability 43, 630–633.

Shea, J., Davis, Z., Brown, K., 2001. Experimental tests of middle palaeolithic spear points using a calibrated crossbow. Journal of Archaeological Science 28, 807–816.

Shi, H., Dong, Y., Wen, B., Xiao, C.-J., Underhill, P.A., Shen, P., Chakraborty, R., Jin, L., Su, B., 2005. Y-chromosome evidence of southern origin of the east asian–specific haplogroup O3-M122. The American Journal of Human Genetics 77, 408–419.

Suárez, R., Cardillo, M., 2019. Life history or stylistic variation? A geometric morphometric method for evaluation of fishtail point variability. Journal of Archaeological Science: Reports 27, 101997.

Thulman, D.K., 2012. Discriminating paleoindian point types from florida using landmark geometric morphometrics. Journal of Archaeological Science 39, 1599–1607.

Toebe, M., Machado, L.N., Tartaglia, F.L., CARVALHO, J.O., Bandeira, C.T., CARGNELUTTI, A., 2018. Sample size for estimating mean and coefficient of variation in species of crotalarias. Anais da Academia Brasileira de Ciências 90, 1705–1715.

Vangel, M.G., 1996. Confidence intervals for a normal coefficient of variation. The American Statistician 50, 21–26.

VanPool, T.L., Leonard, R.D., 2011. Quantitative analysis in archaeology. John Wiley & Sons.

Wierer, U., 2013. Variability and standardization: The early gravettian lithic complex of grotta paglicci, southern italy. Quaternary International 288, 215–238.

Wood, J., Fitzhugh, B., 2018. Wound ballistics: The prey specific implications of penetrating trauma injuries from osseous, flaked stone, and composite inset microblade projectiles during the pleistocene/holocene transition, alaska USA. Journal of archaeological science 91, 104–117.

Yaroshevich, A., Zaidner, Y., Weinstein-Evron, M., 2016. Projectile damage and point morphometry at the early middle paleolithic misliya cave, mount carmel (israel): Preliminary results and interpretations, in: Multidisciplinary Approaches to the Study of Stone Age Weaponry. Springer, pp. 119–134.

### Colophon

This report was generated on 2022-10-16 12:29:04 using the following computational environment and dependencies:

─ Session info ───────────────────────────────────────────────────────────────  
 setting value  
 version R version 4.2.1 (2022-06-23)  
 os macOS Big Sur ... 10.16  
 system x86\_64, darwin17.0  
 ui X11  
 language (EN)  
 collate en\_US.UTF-8  
 ctype en\_US.UTF-8  
 tz America/Los\_Angeles  
 date 2022-10-16  
 pandoc 2.18 @ /Applications/RStudio.app/Contents/MacOS/quarto/bin/tools/ (via rmarkdown)  
  
─ Packages ───────────────────────────────────────────────────────────────────  
 ! package \* version date (UTC) lib source  
 abind 1.4-5 2016-07-21 [1] CRAN (R 4.2.0)  
 P assertthat 0.2.1 2019-03-21 [?] CRAN (R 4.2.0)  
 P backports 1.4.1 2021-12-13 [?] CRAN (R 4.2.0)  
 P beeswarm 0.4.0 2021-06-01 [?] CRAN (R 4.2.0)  
 P bit 4.0.4 2020-08-04 [?] CRAN (R 4.2.0)  
 P bit64 4.0.5 2020-08-30 [?] CRAN (R 4.2.0)  
 bitops 1.0-7 2021-04-24 [2] CRAN (R 4.2.0)  
 boot 1.3-28 2021-05-03 [2] CRAN (R 4.2.1)  
 P broom 1.0.0 2022-07-01 [?] CRAN (R 4.2.0)  
 P cachem 1.0.6 2021-08-19 [?] CRAN (R 4.2.0)  
 P callr 3.7.1 2022-07-13 [?] CRAN (R 4.2.0)  
 P car 3.1-0 2022-06-15 [?] CRAN (R 4.2.0)  
 P carData 3.0-5 2022-01-06 [?] CRAN (R 4.2.0)  
 P cellranger 1.1.0 2016-07-27 [?] CRAN (R 4.2.0)  
 P cli 3.3.0 2022-04-25 [?] CRAN (R 4.2.0)  
 codetools 0.2-18 2020-11-04 [2] CRAN (R 4.2.1)  
 P colorspace 2.0-3 2022-02-21 [?] CRAN (R 4.2.0)  
 P cowplot \* 1.1.1 2020-12-30 [?] CRAN (R 4.2.0)  
 P crayon 1.5.1 2022-03-26 [?] CRAN (R 4.2.0)  
 cvcqv \* 1.0.1 2022-08-05 [1] Github (MaaniBeigy/cvcqv@9093a16)  
 P cvequality \* 0.2.0 2019-01-07 [?] CRAN (R 4.2.0)  
 P DBI 1.1.3 2022-06-18 [?] CRAN (R 4.2.0)  
 P dbplyr 2.2.1 2022-06-27 [?] CRAN (R 4.2.0)  
 P DEoptimR 1.0-11 2022-04-03 [?] CRAN (R 4.2.0)  
 P devtools 2.4.4 2022-07-20 [?] CRAN (R 4.2.0)  
 P digest 0.6.29 2021-12-01 [?] CRAN (R 4.2.0)  
 P dplyr \* 1.0.9 2022-04-28 [?] CRAN (R 4.2.0)  
 ellipse 0.4.3 2022-05-31 [1] CRAN (R 4.2.0)  
 P ellipsis 0.3.2 2021-04-29 [?] CRAN (R 4.2.0)  
 P evaluate 0.15 2022-02-18 [?] CRAN (R 4.2.0)  
 P factoextra \* 1.0.7 2020-04-01 [?] CRAN (R 4.2.0)  
 P fansi 1.0.3 2022-03-24 [?] CRAN (R 4.2.0)  
 P farver 2.1.1 2022-07-06 [?] CRAN (R 4.2.0)  
 P fastmap 1.1.0 2021-01-25 [?] CRAN (R 4.2.0)  
 P forcats \* 0.5.1 2021-01-27 [?] CRAN (R 4.2.0)  
 foreign 0.8-82 2022-01-16 [2] CRAN (R 4.2.1)  
 P fs 1.5.2 2021-12-08 [?] CRAN (R 4.2.0)  
 P gargle 1.2.0 2021-07-02 [?] CRAN (R 4.2.0)  
 P generics 0.1.3 2022-07-05 [?] CRAN (R 4.2.0)  
 P ggbeeswarm \* 0.6.0 2017-08-07 [?] CRAN (R 4.2.0)  
 ggbiplot \* 0.55 2022-08-22 [1] Github (vqv/ggbiplot@7325e88)  
 ggfortify \* 0.4.14 2022-08-22 [1] Github (sinhrks/ggfortify@8e3e7df)  
 ggmap \* 3.0.0 2019-02-05 [2] CRAN (R 4.2.0)  
 P ggplot2 \* 3.3.6 2022-05-03 [?] CRAN (R 4.2.0)  
 P ggpubr 0.4.0 2020-06-27 [?] CRAN (R 4.2.0)  
 P ggrepel \* 0.9.1 2021-01-15 [?] CRAN (R 4.2.0)  
 P ggsignif 0.6.3 2021-09-09 [?] CRAN (R 4.2.0)  
 P glue 1.6.2 2022-02-24 [?] CRAN (R 4.2.0)  
 P googledrive 2.0.0 2021-07-08 [?] CRAN (R 4.2.0)  
 P googlesheets4 1.0.0 2021-07-21 [?] CRAN (R 4.2.0)  
 P gridExtra 2.3 2017-09-09 [?] CRAN (R 4.2.0)  
 P gtable 0.3.0 2019-03-25 [?] CRAN (R 4.2.0)  
 P haven 2.5.0 2022-04-15 [?] CRAN (R 4.2.0)  
 P here 1.0.1 2020-12-13 [?] CRAN (R 4.2.0)  
 P highr 0.9 2021-04-16 [?] CRAN (R 4.2.0)  
 P hms 1.1.1 2021-09-26 [?] CRAN (R 4.2.0)  
 P htmltools 0.5.3 2022-07-18 [?] CRAN (R 4.2.0)  
 P htmlwidgets 1.5.4 2021-09-08 [?] CRAN (R 4.2.0)  
 P httpuv 1.6.5 2022-01-05 [?] CRAN (R 4.2.0)  
 P httr 1.4.3 2022-05-04 [?] CRAN (R 4.2.0)  
 jpeg 0.1-9 2021-07-24 [2] CRAN (R 4.2.0)  
 P jsonlite 1.8.0 2022-02-22 [?] CRAN (R 4.2.0)  
 P knitr 1.39 2022-04-26 [?] 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)  
 lattice 0.20-45 2021-09-22 [2] CRAN (R 4.2.1)  
 legendMap \* 1.0 2022-08-28 [1] Github (3wen/legendMap@707f00c)  
 P lifecycle 1.0.1 2021-09-24 [?] CRAN (R 4.2.0)  
 limma 3.52.2 2022-06-21 [1] Bioconductor  
 P lubridate 1.8.0 2021-10-07 [?] CRAN (R 4.2.0)  
 P magrittr \* 2.0.3 2022-03-30 [?] CRAN (R 4.2.0)  
 maps \* 3.4.0 2021-09-25 [2] CRAN (R 4.2.0)  
 P maptools \* 1.1-4 2022-04-17 [?] CRAN (R 4.2.0)  
 MBESS 4.9.1 2022-07-11 [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 \* 1.8 2021-08-08 [?] CRAN (R 4.2.0)  
 P modelr 0.1.8 2020-05-19 [?] CRAN (R 4.2.0)  
 P munsell 0.5.0 2018-06-12 [?] CRAN (R 4.2.0)  
 P patchwork \* 1.1.1 2020-12-17 [?] CRAN (R 4.2.0)  
 pillar 1.8.1 2022-08-19 [1] CRAN (R 4.2.0)  
 P pkgbuild 1.3.1 2021-12-20 [?] CRAN (R 4.2.0)  
 P pkgconfig 2.0.3 2019-09-22 [?] CRAN (R 4.2.0)  
 P pkgload 1.3.0 2022-06-27 [?] CRAN (R 4.2.0)  
 P plyr \* 1.8.7 2022-03-24 [?] CRAN (R 4.2.0)  
 png 0.1-7 2013-12-03 [2] CRAN (R 4.2.0)  
 P prettyunits 1.1.1 2020-01-24 [?] CRAN (R 4.2.0)  
 P processx 3.7.0 2022-07-07 [?] 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 1.7.1 2022-06-18 [?] CRAN (R 4.2.0)  
 P purrr \* 0.3.4 2020-04-17 [?] CRAN (R 4.2.0)  
 P R6 2.5.1 2021-08-19 [?] CRAN (R 4.2.0)  
 raster \* 3.5-29 2022-08-14 [2] CRAN (R 4.2.0)  
 P RColorBrewer 1.1-3 2022-04-03 [?] CRAN (R 4.2.0)  
 P Rcpp 1.0.9 2022-07-08 [?] CRAN (R 4.2.0)  
 P readr \* 2.1.2 2022-01-30 [?] CRAN (R 4.2.0)  
 P readxl 1.4.0 2022-03-28 [?] CRAN (R 4.2.0)  
 P remotes 2.4.2 2021-11-30 [?] CRAN (R 4.2.0)  
 P reprex 2.0.1 2021-08-05 [?] CRAN (R 4.2.0)  
 rgeos 0.5-9 2021-12-15 [2] CRAN (R 4.2.0)  
 RgoogleMaps 1.4.5.3 2020-02-12 [2] CRAN (R 4.2.0)  
 rjson 0.2.21 2022-01-09 [2] CRAN (R 4.2.0)  
 P rlang 1.0.4 2022-07-12 [?] CRAN (R 4.2.0)  
 P rmarkdown 2.14 2022-04-25 [?] 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 rstatix 0.7.0 2021-02-13 [?] CRAN (R 4.2.0)  
 P rstudioapi 0.13 2020-11-12 [?] CRAN (R 4.2.0)  
 P rvest 1.0.2 2021-10-16 [?] CRAN (R 4.2.0)  
 scales \* 1.2.1 2022-08-20 [1] CRAN (R 4.2.0)  
 SciViews 0.9-13.1 2019-11-16 [1] CRAN (R 4.2.0)  
 P sessioninfo 1.2.2 2021-12-06 [?] CRAN (R 4.2.0)  
 P shiny 1.7.2 2022-07-19 [?] CRAN (R 4.2.0)  
 P sp \* 1.5-0 2022-06-05 [?] CRAN (R 4.2.0)  
 P stringi 1.7.8 2022-07-11 [?] CRAN (R 4.2.0)  
 stringr \* 1.4.1 2022-08-20 [1] CRAN (R 4.2.1)  
 terra 1.6-7 2022-08-07 [2] CRAN (R 4.2.0)  
 P tibble \* 3.1.8 2022-07-22 [?] CRAN (R 4.2.0)  
 P tidyr \* 1.2.0 2022-02-01 [?] CRAN (R 4.2.0)  
 P tidyselect 1.1.2 2022-02-21 [?] CRAN (R 4.2.0)  
 P tidyverse \* 1.3.2 2022-07-18 [?] 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)  
 P utf8 1.2.2 2021-07-24 [?] CRAN (R 4.2.0)  
 P vctrs 0.4.1 2022-04-13 [?] CRAN (R 4.2.0)  
 P vipor 0.4.5 2017-03-22 [?] CRAN (R 4.2.0)  
 P vroom 1.5.7 2021-11-30 [?] CRAN (R 4.2.0)  
 P withr 2.5.0 2022-03-03 [?] CRAN (R 4.2.0)  
 P xfun 0.31 2022-05-10 [?] 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)  
 P yaml 2.3.5 2022-02-21 [?] CRAN (R 4.2.0)  
  
 [1] /Users/gayoungp/Library/Caches/org.R-project.R/R/renv/library/CTtps-76e27b9c/R-4.2/x86\_64-apple-darwin17.0  
 [2] /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/gayoungp/CTtps  
Remote: master @ origin (https://github.com/parkgayoung/CTtps.git)  
Head: [6ed2d7b] 2022-10-16: add doi