Variation in use of East Asian Late Paleolithic weapons: A study of tip cross-sectional area of stemmed points from Korea

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The introduction of blade technology, stemmed points, end scrapers, burins, denticulates, and finer grained materials characterizes the transition from the Early to Late Paleolithic in Korea. Stemmed points have been considered a representative tool that led this set of changes. In this research, we examine the possible role that stemmed points played during the technological transition, as well as throughout the Late Paleolithic. Our main questions are: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns in stemmed point use? We measured tip cross-sectional area (TCSA) to discriminate different likely use classes of projectile points, for example, as poisoned arrow tips or as stabbing spears. We analyzed TCSA with other variables including raw materials, weight, radiocarbon dates and locations. Our results show that the stemmed points were could have served as javelin tips and stabbing spear tips, with smaller numbers as dart tips and un-poisoned arrow tips. TCSA values are controlled mostly by size rather than raw material types. We found different TCSA range of stemmed points at different sites, which could indicate people used stemmed points in different ways depending on the local environment. Some sites show a wide range of TCSA values that represent multi-purpose usage of stemmed points. The temporal pattern of TCSA values is one of little change throughout the Late Paleolithic period but points were mainly produced before Last Glacial Maximum (LGM). We observed that stemmed points were mostly located in certain ecoregions in Korea but no clear spatial pattern is confirmed. We conclude that stemmed points were multi-functional tools, with many likely designed for javelin and stabbing spear tips.

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# Introduction

The introduction of new stone artifact technologies marks a major transition in the Korean Paleolithic from the Early to the Late Paleolithic periods. The transition includes the appearance blade technology, stemmed points, end scrapers, burins, denticulates, etc (Bae et al., 2017; Bae, 2017; Lee et al., 2017; Nakazawa and Bae, 2018; Seong and Bae, 2016). Stemmed points are considered the first evidence of a suite of new technologies defining the Late Paleolithic in this region (Seong, 2008; Seong and Bae, 2016). This is related to the fact that stemmed points appear to originate from Korea and spread throughout Northeast Asia, and they have a close association with mobility, site formation, and occupation diversity (Chong, 2021; O’Driscoll and Thompson, 2018; Park and Marwick, 2022). Despite the importance of stemmed points, only a few studies to date have examined their likely uses. Previous work has mostly discussed their origin, the chronology of the Korean Late Paleolithic, and their relationship with the Japanese archipelago (Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).(Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).

To understand the roles that stemmed points played in the technological transition, this study examines the possible uses of stemmed points. We use the tip cross-sectional area (TCSA) metric to infer potential variability in weapon-use strategies, and compare the results to other archaeological and ethnographic assemblages based on the idea that different shapes correspond to different weapon types (Lombard, 2021). We then explore the relationship between the TCSA range and raw materials, artifact size and discard location, and how these change over time. Our main questions are: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns in stemmed point uses? As part of our discussion, we examine possible connections between the roles of stemmed points and environmental change or population dynamics during the Late Paleolithic period. In order to understand how a certain weapon-tip type was chosen, we apply an evolutionary perspective with the assumption that people chose their weapon tip types as part of their adaptation to the socio-environmental circumstances they found themselves in.

## Stemmed Points in Korea and East Asia

Stemmed points (Sumbejjirugae in Korean) are projectile points made on an elongated blade-like flake or blade with two parallel facets and a single or two arises that converge to form an inverted “Y” (Pratt et al., 2020) ([Figure 1](#fig-sp-hand-made)). Slight retouch is typically located on the proximal end to shape an acute tip and on the distal end to make a stem, which connects to a wooden shaft. Elsewhere in the world these types of artifacts are often called ‘tanged points’, but we prefer ‘stemmed point’ here to distinguish from Bronze Age stone projectile points that have long been called ‘tanged points’ in Korea (Park and Marwick, 2022). Understanding the appearance of stemmed points is relevant to general questions about the origins of projectile technology, the emergence of the Late Paleolithic, and relationships between Korea and adjacent regions in East Asia, such as Japan.

Stemmed points are the first composite tools in the Korean Paleolithic that required two different parts to be one complete tool, consisting of a stone point and shaft, presumably made out of wood (Seong, 2008). Using blades as the blank for the point enables mass production for this composite tool and its shape can become more standardized (Lee, 2015; Park and Marwick, 2022). Therefore, as O’Driscoll and Thompson (2018) claimed, understanding the emergence of projectile technology gives insights to greater cultural, evolutionary, and behavioral cognitive flexibility.

Since stemmed points represent the beginning of the Korean Late Paleolithic, investigating their origins is important for understanding the technological transition from the Early Paleolithic, modern human dispersals into the region, and claims for the existence of the ‘Middle’ Paleolithic in Korea (Bae, 2017; Bae, 2010; Norton and Jin, 2009; Seong and Bae, 2016). Debate about explaining the origin of stemmed points which can be summarized into two competing models: a ‘heterogenic’ migration (Bae, 2010), and an *in situ* evolution model (Seong, 2009). The migration model claims that the new blade industry including stemmed points, and the earlier coarse flake tradition including large cores, polyhedrons, choppers, and even handaxes, came from different origins (i.e. 1: North route: Siberia, Mongolia, or other regions of northeast China, and 2: South route: southern China) as the result of a continuing influx of modern human migration from two routes. The *in situ* model argues that stemmed points and other Late Paleolithic technologies, including blade industries, autonomously emerged in the south of the Korean peninsula, with no apparent external influence. The difference between the two models comes from how to understand a few early sites that contain stemmed points but no blades and blade cores. While the *in situ* model claims that stemmed points appeared before blades by acknowledging those early sites, including Bonggok, Songamri, Yonghodong, and Hwadaeri, the migration model supports the traditional definition of the Late or Upper Paleolithic in Europe and Africa that started with emergence and establishment of blade technology (Seong and Bae, 2016).

Stemmed points are important proxies to understand human behaviors during the Late Paleolithic. Park and Marwick (2022) examined mobility and site occupation patterns by applying concepts of human behavioral ecology to lithic assemblages and found that forager groups using stemmed points may have been associated with the occupation of marginal or extreme environments, compared to groups with no stemmed points. Also, stemmed points were more frequently associated with expedient technologies, indicating residential and less mobile behaviors. Chong (2021) claims that the morphological variation of the stemmed points along with tool types in lithic assemblages, assemblage size, use of raw materials, and types of blanks could represent specific characteristics of occupation such as a “limited activity station” and a “residential base camp.” For example, stemmed points with high morphological variations in a tool size, shape of edge, degrees of damage, and types of edge retouching from Yongsandong site may indicate that the site was used for specific or limited activities such as hunting (Chong, 2021; Kim, 2004; Seong, 2015).

The connection between stemmed points in both Korea and Japan have been studied since the late 1980s as a part of evidence for long-distance/maritime cultural interchanges or social networks (Chang, 2013; Lee, 2015). Stemmed points from the Bonggok site in Korea are currently accepted as the oldest ones among Northeast Asia, dated to ca. 41.5 ka, and made on elongated flakes (Bae et al., 2017; Seong, 2015, 2009). After their first appearance in Korea, stemmed points (Hakuhensenntouki in Japanese) appear in Kyushu, Japan during late Marine isotope stages (MIS) 3. In addition to the stemmed points, there are similar artifacts found in both regions such as microblade cores, Moppule-seokgi (Kakusuijyosekki in Japanese), backed knife, bilateral points, bifacial points, and transport of obsidian (Chang, 2013; Kim and Chang, 2021; Lee, 2015, 2012).

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| Figure 1: Stemmed points from Yongsandong site. 1-6: plain stemmed points, 7-8: one side denticulate stemmed points. |

## Previous studies about the function of stemmed points

Though stemmed points have been generally assumed to have been hunting armatures (Chang, 2013; Lee and Sano, 2019; Lee and Jang, 2011a; Lee and Kong, 2002a; Seong, 2008), it is difficult to understand the likely uses of the tools without knowing their complete shape when attached to other components. Preserved wooden components of projectile tools are too few and rare to standardize the overall scale and variability of the tools used in prehistory (Shea, 2006). Lee and Kong (2002b) claimed stemmed points were generalized ‘stemmed tools’ because of their diverse shapes, which could represent different functions, as well as the uncertainty of complete tool shape. Other researchers propose that non-symmetrical stemmed points, with retouch on one side of the artifact or denticulate blades on one side, should not be called as stemmed points but instead stemmed knives, stemmed side-scrapers, stemmed end-scrapers, or stemmed burins (Kim, n.d.; Lee and Jang, 2011b; Seong, 2008) [Figure 1](#fig-sp-hand-made): 7-8.

Most stemmed points are symmetrical from the tip to the tang, having the central axis function as a line of symmetry (Lee and Jang, 2011b). There are a high proportion of broken tips and stems and the reused tools were repaired based on keeping the symmetry (Kim, 2017; Park, 2013). Studies of stemmed point manufacturing processes and the patterns of broken pieces show that stemmed points may have been used mainly as spear tips (Chang, 2002; Lee, 1985). On Yongsandong site, for example, the percentage of complete tools is only 10%, while the percentage of missing tips is 33%. On Jingeuneul site, the percentages are 16% and 50%, respectively (Park, 2013). In addition to the morphological aspect of stemmed points, investigation of a whole site and tool composition of an assemblage shows that stemmed points or stemmed tools could be strongly associated with hunting activities including peeling the animal skin after slaughtering or separating the bones from the flesh (Chong, 2021; Seong, 2008).

## Tip Cross-Sectional Area

Tip cross-sectional area (TCSA) of stone artifacts has been used as a ballistically relevant standard to probabalistically discriminate different likely use classes of projectile armatures such as spearthrower (a.k.a. atlatl) dart tips, un-poisoned arrow tips and large stabbing/thrusting spears (Lombard, 2022, 2021, 2020; Lombard and Shea, 2021; O’Driscoll and Thompson, 2018; Sisk and Shea, 2011). It is important to note that the TCSA metric alone cannot unambiguously determine artifact function, it only suggests a best-fit ballistic probability for the points if they were hafted as weapon tips. The TCSA metric represents the part of the tool that cuts the target’s hide and relates to weapon flight and penetration dynamics (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). This method was first proposed by Hughes (1998) and and validated by Shea (2006) by comparing archaeological examples to ethnographically collected samples of known use. Shea (2009) also applied this approach to compare projectile points from Africa, the Levant, and Europe, and claimed that projectile weapons first appeared in Africa.

A key advantage of the TCSA metric is its convenience of application: regardless of point type, only maximum width and thickness measurements are needed for calculating the TCSA value (0.5 x maximum width x maximum thickness) (Lombard, 2020; Sisk and Shea, 2011). Later, Sisk and Shea (2011) proposed an alternate metric, tip cross-sectional perimeter (TCSP), for more accurate measure for the force needed to penetrate a target to a lethal depth, while TCSA metric is more associated with cutting aspect. However, TCSP has a few disadvantages that limit its applicability to our case study of Korean stemmed points. The force and penetration depth are not only affected by the stone tip, but also by the mass of the shaft, which cannot be known for most archaeological stone-tipped weapons because they have not been preserved in the archaeological record (Lombard, 2020). Sisk and Shea (2011) also mentioned that TCSP cannot be applied to backed pieces that were hafted as projectile armatures.

Lee and Sano (2019) first applied TCSA to stemmed points from Korea along with use-wear analysis. They analyzed stemmed points from Jingeuneul, located in southwest of Korea, which has the largest number of stemmed points (n = 99) found so far in a single site. For TCSA, they were only able to use 10 stemmed points because they needed to select the stemmed points that retained the widest and thickest part of the specimens for TCSA metric and also displayed diagnostic impact fractures for the use-wear analysis. The purpose of using TCSA in their research was to compare the values to North American dart tips and arrowheads. Their results show that the TCSA range of Jingeuneul stemmed points is relatively wide, overlapping with both North American dart tips and arrowheads. According to their use-wear analysis, a significant number of the stemmed points have diagnostic impact fractures (DIFs) on the surface, likely caused by longitudinal forces from the shaft. They conclude that stemmed points may have been used as spear-throwers or bows. Inspired by Lee and Sano (2019) and TCSA research from lithic assemblages in other parts of the world, we aim to investigate TCSA values for stemmed points from all over South Korea to better understand their likely uses during the Late Paleolithic.

# Methods

## Archaeological sites

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| Figure 2: Korean Paleolithic sites mentioned in this study |

After the first discovery at the Suyanggae site, more than 450 stemmed points have been found in over 30 sites throughout South Korea (Chong, 2021; Lee and Sano, 2019; Sohn, 1967). Most sites contain only a few stemmed points and only a few sites have many more, such as Jingeuneul, Suyanggae (n = 55), and Yongsandong (n = 38) (Kim, 2017). Among these stemmed points, we selected those that retain their widest and thickest parts. We selected stemmed points that were found during field surveys as well as those were from sites that were never dated but were associated with other Late Palaeolithic artifacts. Applying these sampling criteria resulted in a sample of 173 stemmed points from 36 assemblages unearthed from 29 sites spanning the period 44-10 ka ([Figure 2](#fig-map)). The dimensions of the 173 stemmed points were obtained from published excavation reports and by direct measurements during our visits to the collections of local museums and archaeological institutions in Korea.

We distinguished between multiple assemblages at a single site where numerous excavations have been conducted in different locations at the site, and by different institutions under the same site name. For example, Suyanggae site, a registered Korean National Heritage site, has been excavated more than ten times since 1980 by the local university museum and later by archaeological research institutions. There are six different excavation locations that range from a few meters apart to a few kilometers. Similarly, we identified multiple assemblages in a single excavation or even a trench where archaeological 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. As a result, in this research we used four assemblages from Suyanggae. We separated one assemblage among the four by using a different site name, Hajinri, following the convention established the excavators of that location. Hajinri is the sixth excavation location at Suyanggae, which is 3.5 kilometers apart from the other areas and dated to much earlier (around 42-30 ka) than the other assemblages (around 31-15 ka). According to the excavation reports for Hajinri, stemmed points first appeared there around 42 ka with the earliest blade and blade cores (Lee et al., 2018). While we include data from Hajinri here, we consider this assemblage as an unusual outlier because the stemmed points and blades from Hajinri are highly standardized and refined, which are only found at other sites much later in time. We have more confidence in finds from Bonggok, which has the second-earliest dates (41.5 ka) in our collection, as the first appearance of stemmed points. Bonggok includes blades or elongate flakes, but without any accompanying blade cores (Park and Marwick, 2022).

## Investigating patterns in TCSA values

To answer our research questions about the likely uses of stemmed points, we calculated TCSA values for the stemmed points in our sample, and explored the interaction of TCSA values with raw materials and artifact size. To examine the temporal patterns in TCSA values we investigated radiocarbon ages associated with the points. We separated the research time period into three phases based on the major climate event during the Late Pleistocene, Last Glacial Maximum (LGM), and examined the distribution of TCSA values before, during and after. We explored the relationship between TCSA values and the location of assemblages by comparing the distributions of TCSA values across ecological and vegetation zones.

Table 1: TCSA range from Lombard (2021 & 2022)

| Weapon type | N of tools | Mean TCSA | SD | TCSA Range |
| --- | --- | --- | --- | --- |
| Poisoned arrow tips | 565 | 11 | 7 | 4-18 |
| Un-poisoned arrow tips | 338 | 32 | 15 | 17-47 |
| Dart tips | 40 | 58 | 18 | 40-76 |
| Javelin tips | 270 | 66 | 24 | 42-90 |
| Stabbing spear tips | 141 | 140 | 60 | 80-200 |

To aid with interpreting our results, we followed the TCSA ranges for different weapon-delivery systems that Lombard et al. (2022) and Lombard (2021) created by summarizing Wadley and Mohapi (2008)’ study of backed microliths and calibrating existing ranges ([Table 1](#tbl-tcsa-ranges)). We excluded 12 artifacts from our dataset with TCSA greater than 250 and thus outside of the range of the comparative data. For this study we include TCSA values from a total of 161 stemmed points from 33 assemblages unearthed from 25 sites.

### Raw materials

Selective use of raw material is a key characteristic of the technological transition of the Korean Late Paleolithic. Prior to the Late Paleolithic, people mostly used quartzite and vein quartz for stone artifacts. Then, finer grained materials were newly added to assemblages for producing the newly introduced tools (Seong, 2004). We analyzed TCSA values of 160 artifacts with raw material information to examine the interaction of raw material types and TCSA values. We categorized rare raw materials, which have less than 10 artifacts, as “Other”.

### Weight

Different sizes of stone artifacts can constrain or enable different functions. Overall size of stone points has been used as a potential proxy to distinguish different armature types (Sahle and Brooks, 2019; Thomas, 1978). We chose weight as a proxy for overall size of the stemmed points. Weight is a reliable discriminator between tools of different sizes and a descriptive attribute which can be measured rapidly and objectively and serve as a criterion of likeness or dissimilarity in projectile point description (Fenenga, 1953; Shea, 2006). We then explored the relationship between weight and raw materials on TCSA values. Excluding points that we were not able to measure or obtain the records of their weight, we explored the relationship between TCSA and weight for 152 artifacts.

### Temporal patterns

We used radiocarbon ages to explore the temporal patterns of the likely uses of stemmed points. After excluding assemblages that have no radiocarbon dates, we used 26 assemblages dated from 45ka to 14.8ka to explore variation in TCSA over time. We divided the artifacts from dated assemblages into three groups based on the LGM: before, during and after, to examine the impact of this major climate event on TCSA values.

### Spatial Patterns

We summarized the distribution of TCSA values for each assemblage to examine spatial patterns in TCSA values. Among 25 artifacts, we combined sites that contains fewer than 5 stemmed points aside and named them as “Other”. We explored possible effect of environmental variation on TCSA values by grouping stemmed points by the eco-regional zones that they were found in, and comparing the distributions of TCSA values across the different zones. We compared distributions across four vegetation zones, and also across 16 zones of different geographical characteristics.

For the vegetation zones we used Yi and Kim (2010)’s divisions of South Korea into three zones: Central Temperate Zone (CT), South Temperate Zone (ST), and Subtropical-warm Temperate Zone (SWT). These divisions are based on Yim and Kira (1975)’s forest vegetation map, defined by recent temperature and precipitation values.

We also explored spatial patterns using 16 geographical zones based geographical characteristics such as inland, coastal, major rivers, island, and major mountain ranges in addition to ecological information including temperature and precipitation (Lee et al., 2008). The sites in our sample occur in 14 of these zones: Imjin river basin (IRB), Metropolitan (MP), Central inland (CI), Kangwon coastal (KC), Choongnam coastal (CC), Southwestern inland (SWI), Upper Nagdong river basin (UNRB), WoolYoung coastal (WYC), Western Cholla (WC), Southern mountain (SM), Southeastern inland (SEI), Hyungsan Taewha coastal (HTC), Western south coastal (WSC), and Eastern south coastal (ESC). We then located individual assemblages on those two maps using longitudes and latitudes and explore TCSA values for each zone. We recognize that modern eco-regional maps may not fully resemble the Pleistocene landscape in which the points were made and used, however these are the only maps of eco-regional zones that are currently available.

## Modelling weapon-tip type selection

The process of the introduction of new technologies can vary depending on the environmental and social contexts of the transmission of the manufacturing techniques for the new tools. Moreover, the new tools themselves can alter the typical contexts of tool use. For example, the introduction of the bow and arrow in American enabled individuals to work without hunting in teams and provided opportunities for non-elite hunters to produce their own subsistence or pursue individual wealth (Angelbeck and Cameron, 2014; Bettinger, 2013; Rorabaugh and Fulkerson, 2015). Taking an evolutionary approach, we assume that, given an opportunity to explore alternative technologies, human groups carefully selected a specific stone tool technology based on its advantages over other alternatives, according to their performance in a variety of domains, such as physical and social functions (Lombard et al., 2022). Thus, the selection of weapon-tip types is likely to reflect the socio-environmental circumstances that people encountered and managed. For example, Eren et al. (2022) used TCSA to compare the morphological variance of Clovis and Folsom points and claimed that Clovis points were more variable in shape than Folsom points because Clovis foragers were exposed to largely unfamiliar landscape. Clovis points were used as multifunctional tools that performed a wider range of tasks, including cutting and sawing. Folsom points, on the other hand, show a narrower range of variation, indicating a they were more likely used for specific tasks.

Inspired by Eren et al. (2022)’s approach, we hypothesized some simple scenarios that might explain the temporal and spatial patterns of TCSA range in Korea. If stemmed points have a narrow range of TCSA values, then people likely produced tools that performed a small set of specific tasks. This may be related to low levels of uncertainty in the forager’s social and physical environments. On the other hand, a wide range of TCSA values may indicate that stemmed points were multifunctional tools, suggesting that people were responding to unfamiliar situations, such as moving into an unfamiliar landscape or unpredictable variation in patch productivity and travel times (Bettinger and Grote, 2016; Bird and O’Connell, 2006; Kelly, 2007).

We predict a temporal pattern of more variable TCSA values at the first appearance of stemmed points, suggesting that people were using the tools as part of an adaptation to moving into unfamiliar landscapes, with unpredictable variation in patch productivity and travel times. We predict a further increase in the variability of TCSA values in the LGM as lower temperatures alter the distribution of resources and lower the predictability of resource encounters. After the LGM we predict a reduction in the range of TCSA values, with higher temperatures and increased bioproductivity.

We predict that TCSA values vary across vegetation types and geographical zones in response to heterogeneously distributed food resources. In harsh environments with lower patch productivity, similar to the case of LGM duration, we predict a further increase in the variability of TCSA values. On the other had, we predict a reduction in the range of TCSA values in affluent patches with predictable types of prey. In their study of hunter-gatherer mobility strategies, Hamilton et al. (2016) show that resources are abundant and predictable along coasts or lake shores, which is highly dependent on temperature and precipitation and thus hunter-gatherers often become effectively sedentary. Our prediction is that the range of TCSA values will be narrower in coastal areas such as ST and SW of vegetation zones and ESC of geographical zones than in inland areas such as CT of vegetation zones and CI of geographical zones.

The entire R code (Core, 2021) and data files used for all the analysis and visualizations contained in this paper is openly available at https://doi.org/10.17605/osf.io/dqna8 to enable re-use of materials and improve reproducibility and transparency (Marwick, 2017). All of the figures, tables, statistical test results presented here in addition to the raw data can be independently reproduced with the code and data in this repository. The code is released under the MIT license, the data as CC-0, and figures as CC-BY, to enable maximum re-use.

# Results

## TCSA range of Korean stemmed points

[Figure 3](#fig-tcsa-all-sp) shows TCSA values for all stemmed points in our sample, with shaded rectangles to assist in the interpretation of their likely uses. Overall we see a wide variation of TCSA values. The sample mean TCSA is 95.5, and standard deviation of TCSA is 44.1. According to the TCSA ranges presented in [Table 1](#tbl-tcsa-ranges), Korean stemmed points are overall mostly in the categories of javelin tips and stabbing spear tips, with smaller numbers as dart tips and un-poisoned arrow tips. Among the weapon-tip types, only poison arrow tips appear to be absent from these Korean assemblages.

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| Figure 3: Distribution of TCSA values for all Korean stemmed points in the current dataset. Shaded boxes indicate TSCA ranges for various weapon types. |

## Variation in TCSA values by artifact size

Using weight as a size proxy we examined the relationship between size and likely use of the stemmed points inferred from TCSA values. We conducted a univariate cluster analysis (Song and Zhong, 2020; Wang and Song, 2011) of stemmed points by weight and it revealed three clusters of artifact sizes (A of [Figure 4](#fig-artifact-size-cluster), mean = 10.1, SD = 7.3). Cluster 1, the smallest (lightest) artifacts, have a lower range of TCSA values, compared to Cluster 2 (B of [Figure 4](#fig-artifact-size-cluster), mean = 94.5, SD = 42.8). TCSA values for Cluster 3 are the highest, except for one artifact, which is lower than 50. There are a few overlaps, but we can still assume that artifacts in different size clusters might be made for different purposes.

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| Figure 4: A. Distribution of artifact weight showing three clusters. B. TCSA values for all artifacts. Artifact size classes indicated by the digits representing data point values |

## Variation in TCSA values by raw material

[Figure 5](#fig-tcsa-raw-materials) shows that about half of the stemmed points were made from shale and its TCSA range is widely distributed. Acidic volcanic rocks tend to have skewed lower TCSA values. The other raw materials including hornfels, rhyolite, and tuff show a wide distribution, similar to shale. The category of “Other” raw materials include porphyry, trachyte, felsite, chert, quartz, quartzite, granite, mudstone, and unidentified rocks. Overall, there is no clear pattern of TCSA among raw materials.

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| Figure 5: TCSA values by lithic raw material. |

[Figure 6](#fig-tcsa-size) shows a positive relationship between TCSA, raw material and artifact weight. There is a stronger correlation between TCSA and artifact weight for acidic volcanic points (i.e. points are closer to the regression line), whereas the correlation for shale stemmed points is weaker. The other raw materials show various distribution patterns around the regression line, confirming that raw material appears not to have strongly influenced TCSA (see also [Figure 5](#fig-tcsa-raw-materials)).

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| Figure 6: Artifact size and TSCA values by lithic raw material |

## Temporal patterns of TCSA values

[Figure 7](#fig-tcsa-radio-carbon) shows 26 assemblages with stemmed points in chronological order (panel A). Assemblages discarded before LGM tend to possess more stemmed points, such as Suyanggae. These assemblages have a wide range of TCSA values, indicating multiple likely usages of stemmed points. Overall, there is no clear pattern in these assemblages over time. The TCSA range varies depending on the assemblages.

Panel B of [Figure 7](#fig-tcsa-radio-carbon) shows the distribution of TSCA values from assemblages dating to before the LGM, during the LGM, and after, to explore the impact of climate change on the probably function of the artifacts. Our results show that stemmed points were made predominantly before LGM and only a few left after LGM. Each category shows wide variation in LGM, which indicates diverse uses of stemmed points. While the median TSCA value for assemblages discarded during the LGM is higher than assemblages from earlier and later, there is no statistically significant difference in TCSA values across the three periods (*F*(2, 139) = 0.92, *p* = .400).

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| Figure 7: A: Distribution of TCSA values over time. The light gray shade indicates Marine isotope stages (MIS) 3, the gray shade indicates MIS 2 and the darkest shade indicates the duration of LGM. B: Distribution of TCSA values grouped by LGM event |

## Spatial patterns of TCSA values

We computed artifact TCSA values for 25 sites that contain more than 5 stemmed points to observe variation between sites ([Figure 8](#fig-tcsa-per-sites)). Sites with fewer than 5 stemmed points were grouped under the category of “Other”. Among the sites in our sample, Suyanggae has the most stemmed points and the widest range of TCSA values. This suggests that people made stemmed points for accomplishing a variety of tasks at Suyanggae site. Nosanri, Sibuk, and Wolpyeng have a narrower range of lower values, which indicates less diverse likely uses for stemmed points. Yongsujaeul shows a narrower range but higher TCSA value. Yongsandong has the second most stemmed points and shows roughly two different clusters of TCSA values.

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| Figure 8: TCSA values by archaeological site. |

In order to explore spatial patterns and the relationship between the role of stemmed points and the environment, we located individual assemblages on maps that depict eco-regional zones. Our results show that stemmed points are only located in certain zones, Central Temperature Zone (CT) of vegetation map or Central inland (CI) ([Figure 9](#fig-gis-tcsa-sites) panel A & D) of eco-region map. We observed that there are statistically significant differences in the distributions of TCSA values between some zones (Vegetation zones: *F*(2, 140) = 4.27, *p* = .016, Ecoregion zones: *F*(6, 136) = 2.58, *p* = .021). The Tukey’s HSD results show that TCSA values from the South Temperature Zone (ST) zone are significantly different from the other two vegetation zones ([Figure 9](#fig-gis-tcsa-sites) panel C). Looking into this further, we see that there are only six artifacts from the ST zone, with only three of these having TSCA values above 175. The other three have TCSA values lower than 100, similar to the other zones ([Figure 9](#fig-gis-tcsa-sites) panel B). Given the small number of artifacts with extreme TCSA values in the ST zone, we hesitate to conclude this is an archaeologically significant pattern of different TCSA values. The Tukey HSD pairwise differences show no pairs of eco-regions with significant differences in TCSA values ([Figure 9](#fig-gis-tcsa-sites) panel F). Overall, our results indicate no clear patterns in the distribution of TCSA values across the vegetation and eco-regional zones.

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| Figure 9: TCSA values by assemblages and ecoregions. A: Modern vegetation map defined by temporature and precipitation. The individual points indicate assemblages. B: TCSA distribution for vegitation zones. The individual points indicate artifacts. C: Tukey test result for vegitation zones. D: Ecoregion map based on geographical boundaries and ecological conditions (modified the map from Lee et al. (2008)). E: TCSA distribution for ecoregion zones, excluding zones with no artifacts. F: Tukey test result for ecoregion zones |

# Discussion

To investigate the role that stemmed points played in the technological transition during the Korean Late Paleolithic, we computed the TCSA metric to infer likely uses by comparing the results to the TCSA range from other archaeological and ethnographic cases ([Table 1](#tbl-tcsa-ranges)). Our main questions were: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns in stemmed point uses?

Our results show that javelin tips and stabbing spear tips are the most probable ballistic uses for stemmed points. There are a few stemmed points in our sample that may have been used as dart tips and un-poisoned arrow tips. None have TCSA values in the range of poison arrow tips ([Figure 3](#fig-tcsa-all-sp)). Lee and Sano (2019) computed TCSA for 10 stemmed points from Jingeuneul site, which we were not able to include in this research due to data availability, and concluded that their TCSA values fall within the range of North American dart tips and arrowheads. In general, we found a wide range of TCSA in our sample, indicating that stemmed points might play diverse roles in foraging toolkits.

TCSA can be impacted by other factors such as raw materials and portability. Eren et al. (2022) explain that smaller TCSA could be the result of pursuing production economy and transport efficiency. We explore the relationship between TCSA and raw material types and weight in order to examine these factors. We observed no clear pattern for raw materials ([Figure 5](#fig-tcsa-raw-materials)) but weight ([Figure 4](#fig-artifact-size-cluster)), though weight is correlated with raw materials ([Figure 6](#fig-tcsa-size)). Therefore we could assume that raw materials also associated with TCSA value. We found that different clusters of weight are matched with different types of weapon tips ([Figure 4](#fig-artifact-size-cluster)).

The TCSA varies from assemblages to assemblages without any discernible temporal pattern in functional use ([Figure 7](#fig-tcsa-radio-carbon) panel A). But the stemmed points mainly used before LGM ([Figure 7](#fig-tcsa-radio-carbon) panel B). While we predicted the greatest variation in TCSA values during the LGM, we found that variability decreased during the LGM in comparison to the previous period. This could be explained by the overall massive decline in stemmed points usage. We found that stemmed points are only located in certain eco-regional zones such as Central Temperature zone without any clear pattern in TCSA function ([Figure 9](#fig-gis-tcsa-sites)). However, as predicted, TCSA values in inland areas such as CT of vegetation zones show higher variability. Based on the results, we assume that stemmed points performed a wider range of tasks in low-productivity patches. Both temporal and spatial analyses show that stemmed points were made for a particular environment, not so much harsh as LGM. Prates et al. (2022) claimed that fishtail projectile points in South America was used for megafauna hunting and contributed to their extinction by proving strong relationship between the temporal density and spatial distribution of megafauna and the projectile points. Our results support this claim by showing the dense distribution of stemmed point in certain environment.

Our models premise that the choice of weapon-tip types reflects the socio-environmental circumstances. To examine the possible connections between the roles of stemmed points and environmental change or population dynamics during the Late Paleolithic period, we compared the temporal and spatial patterns of TCSA to results of simulated Mean Annual Temperature (MAT) and Summed probability distribution (SPD) from Park and Marwick (2022). The simulated temperature distribution in south Korea during the Late Paleolithic period (Figure 9: A from Park and Marwick (2022)) seems similar to the modern eco-regional zones that we used in this research ([Figure 9](#fig-gis-tcsa-sites) panel A & D). Figure 9: C from Park and Marwick (2022) shows the slow decrease of temperature until the end of LGM, which could explain our results of temporal pattern, meaning stemmed points were used during the cooler environment with a temperature between 4 and 6 ℃. Results of SPD (Figure 10 from Park and Marwick (2022)) show several peaks, as indicated by the positive deviations from the three null models (shaded in red), and downs (shaded in blue), but no drastic growth or decline during our research period, indicating no major impact from population dynamics on stemmed points.

Overall, our temporal and spatial patterns of TCSA show a wide TCSA range throughout the Late Paleolithic period and between eco-regional zones. Especially, we confirmed the widest TCSA range in a single site, Suyanggae ([Figure 8](#fig-tcsa-per-sites)). As a consequence, our results are consistent with our second scenario in which stemmed points are described as multifunctional tools, suggesting that people created stemmed points in response to unexpected or varying circumstances in their habitats, similar to Clovis points (Eren et al. (2022)).

# Conclusion

Considering the importance of stemmed points for the technological transition during the Late Paleolithic in Korea, our research examines the likely uses of stemmed points by asking three research questions: What were the best-fit ballistic probabilities for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal and spatial patterns of stemmed point use? We applied the tip cross-sectional area (TCSA) metric because it has been used as a ballistically relevant standard to discriminate different likely use classes of projectile points and it requires only a few measurements on a stone artifact (i.e. width and thickness) to compute the metric. We calculated TCSA for a total of 161 stemmed points from 33 assemblages unearthed from 25 sites. Then we examined the TCSA values with other variables including raw materials, weight, radiocarbon dates, and site locations. Based on the evolutionary approach, we premised that the way of using stemmed points is likely to reflect the socio-environmental circumstances that people encountered and managed. We examined the possible impact of LGM on stemmed points and their distribution on eco-regional maps.

According to the different weapon-delivery systems that summarize TCSA of projectile points from archaeological and ethnographic cases, a majority of stemmed points might be used the most likely as javelin tips and stabbing spear tips. In general, though, we noted a wide range and also differing distribution of TCSA in each assemblage. Therefore, we conclude that stemmed points might play diverse roles during the Late Paleolithic. From our findings, we infer that people were exposed to an unfamiliar situation and used a stemmed point as a multifunctional tool to carry out multiple tasks. We are aware that discriminating the likely use of small projectile points could be arbitrary (Erlandson et al., 2014). Since TCSA covers the critical elements of projectiles, flight and penetration dynamics (i.e. increased or decrease by shape of tip and cross section), we still consider it a useful metric for discriminating between weapon tip tools (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). As part of our future research, we will conduct usewear analyses of stemmed points and experimental research in an effort to elucidate the detailed function of stemmed points and technological links between hunter-gatherer groups.

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# CRediT authorship contribution statement

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

Marlize Lombard: Conceptualization, Methodology, Supervision

Donghee Chong: Data curation

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

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### Colophon

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 terra 1.6-47 2022-12-02 [1] CRAN (R 4.2.0)  
 tibble \* 3.1.8 2022-07-22 [1] CRAN (R 4.2.0)  
 tidyr \* 1.2.1 2022-09-08 [1] CRAN (R 4.2.0)  
 tidyselect 1.2.0 2022-10-10 [1] CRAN (R 4.2.0)  
 tidyverse \* 1.3.2 2022-07-18 [1] CRAN (R 4.2.0)  
 timechange 0.1.1 2022-11-04 [1] CRAN (R 4.2.0)  
 tzdb 0.3.0 2022-03-28 [1] CRAN (R 4.2.0)  
 units 0.8-0 2022-02-05 [1] CRAN (R 4.2.0)  
 urlchecker 1.0.1 2021-11-30 [1] CRAN (R 4.2.0)  
 usethis 2.1.6 2022-05-25 [1] CRAN (R 4.2.0)  
 utf8 1.2.2 2021-07-24 [1] CRAN (R 4.2.0)  
 vctrs 0.5.1 2022-11-16 [1] CRAN (R 4.2.0)  
 vipor 0.4.5 2017-03-22 [1] CRAN (R 4.2.0)  
 vroom 1.6.0 2022-09-30 [1] CRAN (R 4.2.0)  
 withr 2.5.0 2022-03-03 [1] CRAN (R 4.2.0)  
 xfun 0.35 2022-11-16 [1] CRAN (R 4.2.0)  
 xml2 1.3.3 2021-11-30 [1] CRAN (R 4.2.0)  
 xtable 1.8-4 2019-04-21 [1] CRAN (R 4.2.0)  
 yaml 2.3.6 2022-10-18 [1] CRAN (R 4.2.0)  
  
 [1] /Library/Frameworks/R.framework/Versions/4.2-arm64/Resources/library  
  
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The current Git commit details are:

Local: master /Users/gayoungp/Desktop/tcsakoreanpaleolithic  
Remote: master @ origin (https://github.com/parkgayoung/tcsakoreanpaleolithic.git)  
Head: [773384f] 2023-02-03: Finished editing results