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 characterises 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 stemmed points used for? How diverse were their likely uses? What are the temporal 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 arrowheads or as thrusting spears. We analyzed TCSA with other variables including raw materials, weight, site and radiocarbon dates. Our results show that the stemmed points were likely used as javelins and thrusting spear tips, with smaller numbers as dart tips and arrowheads. TCSA values are controlled mostly by size rather than raw material types. We found different usage 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. We conclude that stemmed points were multi-functional tools, with many likely designed for javelin and thrusting spear tips.

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# Introduction

The introduction of new stone artefact 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 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 debated their origin, the chronology of the Korean Late Paleolithic, and their relationship with Japan (Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).(Chang, 2013; Chong, 2021; Lee and Sano, 2019; Park, 2013).

To understand the likely 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 likely artifact use, 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 likely use and raw materials, artifact size and discard location, and how these change over time. Our main questions are: What was the best-fit ballistic probability for the stemmed points if they were hafted as weapon tips? How diverse were their likely uses? What are the temporal patterns in stemmed point uses? As part of our discussion, we examine possible connections between the roles of stemmed points and population dynamics or environmental change 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 depending on their hunting strategies and socio-environmental circumstances.

## Stemmed Points in Korea and East Asia

Stemmed points (Sumbejjirugae) 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). 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). Understanding the emergence of stemmed points is relevant to general questions about the origins of projectile technology, the emergence of the Late Palaeolithic, and relationships to adjacent regions in East Asia, such as Japan.

The stemmed point is the first composite tool in the Korean Paleolithic that requires two different parts, 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, O’Driscoll and Thompson (2018) claims that 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 origin(s) becomes a key for understanding the technological transition from the Early Palaeolithic, modern human dispersals, and claims for the existence of the ‘Middle’ Paleolithic in Korea (Bae, 2017; Bae, 2010; Norton and Jin, 2009; Seong and Bae, 2016). There has been a noteworthy debate about explaining the origin(s) 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 (e.g. 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. The *in situ* model claims that stemmed points appeared before blades by acknowledging those early sites, including Bonggok, Songamri, Yonghodong, and Hwadaeri, while the migration model supports the traditional definition of the Late or Upper Palaeolithic 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 Palaeolithic. 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).

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 (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 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). Stemmed points are thus important for understanding the connections and technological transitions between islands in Japan (Chang, 2013).

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

## Uses of stemmed points

Though stemmed points are 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 generalize the overall scale and variability of the tools used in prehistory (Shea, 2006). Lee and Kong (2002b) claimed stemmed points were ‘stemmed tools’ because of their diverse shapes, which could represent different functions, as well as the uncertainty of complete tool shape. Other researchers agree that some stemmed points that are not symmetrical and have retouch on one side of the artifacts or have denticulate blades on one side should not be called 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). 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). There are a high proportion of broken tips and stems and the reused tools were repaired based on keeping the symmetry (Kim, n.d.; Park, 2013). In addition to the morphological aspect of stemmed points, investigation of the whole site and tool composition of an assemblage shows that stemmed points or stemmed tools are strongly associated with hunting activities including peeling the animal skin after slaughtering or separating the bones from the flesh (Chong, 2021; Seong, 2008).

A recent study conducted use-wear analysis on 95 stemmed points from the Jingeuneul site, along with examining fracture patterns, TCSA, tip cross-sectional perimeter (TCSP), and neck width to understand the use of the tools (Lee and Sano, 2019). Their results show that a considerable number of the stemmed points show diagnostic impact fractures (DIFs) on the surface, which likely occurred due to longitudinal forces from the shaft when a stone tip hits a target. In other words, their research indicates that stemmed points may have been used as spear-throwers or bows (Sano and Oba, 2015).

## Tip Cross-Sectional Area

Tip cross-sectional area (TCSA) of stone artefacts has been used as a ballistically relevant standard to probabalistically discriminate different between functional classes of projectile armatures such as spearthrower (a.k.a. atlatl) dart tips, arrowheads and large stabbing/thrusting spears (Lombard, 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 artefact function, it only suggests a best-fit ballistic probability for the points if they were hafted as weapon tips. The TCSA metric indicates 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 tested 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: 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 measure, 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 (Lombard, 2020). (**sisk2011?**) also mentioned that TCSP cannot be applied to backed pieces that are hafted as projectile armatures.

Lee and Sano (2019) first applied TCSA to stemmed points from Korea along with use-wear analysis. In that study, stemmed points were analysed from Jingeuneul, located in southwest of Korea, which has the largest number of stemmed points (n = 99) ever found in a single site. For TCSA, they were only able to use ten 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. Inspired by Lee and Sano (2019) and TCSA research from lithic assemblages in other parts of the world, we aimed to investigate TCSA values for a large number of stemmed points from all over South Korea to better understand their likely uses during the Late Paleolithic.

# Methods

## Archaeological sites

Since the first evidence of the Korean Late Paleolithic was discovered at Seokjangri site, including blades and a stemmed base, around 300 stemmed points have been found in Korea (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 retained their widest and thickest parts. Our dataset contains stemmed points that were found during field surveys as well as those were from sites that were never dated but were associtaed with other Late Palaeoltihic 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 the Suyanggae site. We separated one assemblage among the four by using a different site name, Hajinri, following the convention established the excavators of that location. Because Hajinri was from the sixth excavation area, which is 3.5 kilometers apart from the other spots 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 in Hajinri around 42 ka with the earliest blade and blade cores (Lee et al., 2018). We consider this assemblage as an unusual outlier because the stemmed points and blades from Hajinri are so early and also so 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).

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

## 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, site location, and artefact size. To examine the temporal patterns in TCSA values we investigated radiocarbon ages associated with the points. We then compared those temporal patterns with demographic and environmental proxies based on summed probability distributions (SPD) and annual temperature changes from Park and Marwick (2022). 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 257 (263-2622) 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 32 assemblages unearthed from 26 sites.

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 |

### 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 used quartzite and vein quartz for core and flake tools. Then, finer grained materials were newly added to assemblages for producing the newly introduced tools (Seong, 2004). We analyzed TCSA values for each raw material type to examine the interaction of raw material types and TCSA values.

### Geographical Patterns

To explore geographical patterns in TCSA values, we retained only sites that contains more than four stemmed points. This resulted in a sample of sites and points. We summarised the distribution of TCSA values for each site to identify variation that might be influenced b environmental differences relating to the different locations of the sites.

### 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 separate 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 determined rapidly and objectively and serve as a criterion of likeness or dissimilarity in projectile point description (Fenenga, 1953; Shea, 2006). Excluding nine 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 pattern

We used radiocarbon ages to explore the temporal pattern of the function of stemmed points. We excluded assemblages that have no radiocarbon dates. We arranged assemblages dated from 45ka to 14.8ka to explore variation in TCSA over time.

## 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 techniques for making the new tools, and 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 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 two basic scenarios that might explain the regional or/and temporal pattern of TCSA range. If stemmed points represent a narrow TCSA range, then people likely produced tools that performed a small set tasks. This may be due to low levels of uncertainty in the forager’s social and physical environments. On the other hand, a wide TCSA range 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 changes in patch productivity and travel times [CITE PAPERS ON ARCHAEOLOGY AND PATCH CHOICE MODEL]. We expect to observe different TCSA ranges, reflecting morphologically and functionally different stemmed points, across different regions or environments in Korea, and over time.

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

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

[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 function. The ranges indicated by the shaded rectangles were taken from Lombard (2021). Overall we see a wide variation of TCSA values in this boxplot. The sample mean TCSA is 95.5, and standard deviation of TCSA is 44.1. According to the TCSA ranges presented in Table 1 of Lombard (2021), Korean stemmed points are overall mostly in the categories of javelins and thrusting spear tips, with smaller numbers as dart tips and arrowheads. Among the weapon-tip types, only poison arrowheads appear to be absent from these Korean assemblages.

## Variation by raw material

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| Figure 4: Histograms of TCSA values by lithic raw material. |

[Figure 4](#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.

## Geographical patterns

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| Figure 5: Histograms of TCSA values by archaeological site. |

We computed artefact TCSA values for sites that contain more than stemmed points to observe variation between sites ([Figure 5](#fig-tcsa-sites)) Sites with fewer than 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 a variety of different purposes in Suyanggae. The TCSA values for Nosanri and Sibuk are have a narrower range of lower values, which indicates less diverse functions for stemmed points. Wolpyeng and Yongsujaeul have similar amounts of stemmed points to Nosanri and Sibuk, but exhibit wider distributions of TCSA values. Yongsandong has the second most stemmed points and TCSA shows a similar distribution to Yongsakul.

## Variation by artefact size and raw material

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 INSERT CITATION TO PAPER ON THIS METHOD of stemmed points by weight and it revealed three clusters of artefact sizes (A of [Figure 6](#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 6](#fig-artifact-size-cluster)). TCSA values for Cluster 3 are the highest, except for one artifact, which is lower than 50 (A of [Figure 6](#fig-artifact-size-cluster), mean = 94.5, SD = 42.8). 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 6: A. Distribution of artefact weight showing three clusters. B. TCSA values for all artefacts with size classes indicated by data point shape. |

We combined the raw material information as another variable for the analysis. [Figure 7](#fig-tcsa-size) shows a positive relationship between TCSA and artifact weight. The relationship varies by raw material types, perhaps due to variation in the density of different lithic raw materials. 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 varied distribution patterns around the regression line, reconfirming that raw material appears not to have strongly influenced TCSA (see also [Figure 4](#fig-tcsa-raw-materials)).

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| Figure 7: Artifact size and TSCA values by lithic raw material |

## Temporal pattern of TCSA values

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| Figure 8: Distribution of TCSA values over time |

We arranged assemblages in chronological order ([Figure 8](#fig-tcsa-radio-carbon)). Our analysis shows that early assemblages (i.e. 45-24 ka) tend to possess more stemmed points, such as Suyanggae, and these have a wide range of TCSA values, indicating multiple likely usages of stemmed points. After about 38 ka stemmed points become less common in archaeological assemblages. Overall, TCSA values from assemblages that have more than stemmed points vary considerably, which makes it difficult to discern a clear temporal pattern in these assemblages.

# 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 artifact uses by comparing the results to other archaeological and ethnographic studies We asked three questions to achieve our research goal: What were stemmed points used for? How diverse were their functions? What are the temporal patterns in stemmed point functions? In our assumptions, human groups were capable of intentionally choosing and designing tools according to their socio-environmental circumstances. We came up with two models: (1) people created stemmed points and used them as a specific type of tool; or (2) they created stemmed points for multifunctional tools.

Our results indicate that javelins and thrusting spear tips are the best matches for stemmed points. There are a few stemmed points that can be used as dart tips and arrowheads, but none of them are suitable for poison arrowheads ([Figure 3](#fig-tcsa-all-sp)). We found stemmed points played a diverse role, by showing a wide range of TCSA values. Some sites, such as Nosanri and Sinbuk, used stemmed points as limited-function tools. Meanwhile, stemmed points were used in multiple ways at other sites, especially Suyanggae. In general, stemmed points played multiple roles in more sites ([Figure 5](#fig-tcsa-sites)). Through the Late Paleolithic period, TCSA values hardly changed ([Figure 8](#fig-tcsa-radio-carbon)). The chronological sequence of TCSA varies from region to region with no clear pattern. Therefore, we conclude that stemmed points were mainly designed for Javelin and thrusting spear tips but they were multi-functional tools.

We are aware of the concern that discriminating the function of small projectile points could be arbitrary work (Erlandson et al., 2014). Because TCSA covers the critical elements of projectiles, flight and penetration dynamics (i.e. increased or decrease by shape of tip and cross section), we consider it a useful metric for discriminating between weapon tip functions (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). Stemmed points have been considered so far as long-distance hunting amateurs pursuing large bodies of prey such as a deer (Chang, 2013; Lee and Sano, 2019; Lee and Jang, 2011a; Lee and Kong, 2002a; Seong, 2008). TCSA enabled us to gain a more detailed understanding of the function of stemmed points.

TCSA can, however, 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. Weight plays an important role in portability and penetration of projectiles (Hughes, 1998). According to our results, raw materials do not have a clear pattern, but weight is strongly correlated with raw materials ([Figure 4](#fig-tcsa-raw-materials) and [Figure 7](#fig-tcsa-size)). Different clusters of weight are matched with different types of weapon tips ([Figure 6](#fig-artifact-size-cluster)). Based on these analyses, we assume that people were able to produce the ideal size tools regardless of raw materials.

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 population dynamics or environmental change during the Late Paleolithic period, we compared the temporal pattern of TCSA to results of Summed probability distribution (SPD) and simulated Mean Annual Temperature (MAT) from Park and Marwick (2022). In those two analyses, -Park and Marwick (2022) covered assemblages with and without stemmed points, which is useful for us to explore the overall socio-environmental dynamics. As we discussed, there is no clear pattern in the temporal or regional pattern of TCSA ([Figure 8](#fig-tcsa-radio-carbon) or [Figure 9](#fig-socio-climate): A). We consider that TCSA, or the function of the stemmed points, are strongly dependent on the surrounding environment or their situation. [Figure 9](#fig-socio-climate): B shows that the temperature slowly decreased until around 22 ka and then went up again with a little range of fluctuations. Temperatures differ significantly between sites, with a maximum difference of 5℃. Results of SPD 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 ([Figure 9](#fig-socio-climate): C). From the climate and population study, we could observe that there is no dominating change but minor and often fluctuations throughout the Late Paleolithic and variations per site. Overall this pattern is well matched with the TCSA results, indicating the people produced stemmed points as multifunctional tools suitable for unexpected or various situations in their habitats similar to the case of Clovis points (Eren et al. (2022)).

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| Figure 9: A.Distribution of TCSA values by time. B.Mean Annual Temperature (MAT) of the Korean Paleolithic assemblages from 50 ka to 10 ka. The gray lines indicate the MAT for each site and the black line is the mean temperature of all sites. The light gray area in the middle of the plot indicates the duration of MIS 2, and the dark gray area represents the duration of the LGM (from Park and Marwick (2022): Figure 9). C. Summed probability distribution (SPD) of 100 radiocarbon dates. The black solid line represents actual radiocarbon ages. The gray shaded region shows the Monte Carlo envelope that encompasses the 95% confidence interval for the null models. The red and blue vertical bands highlight the portions of the SPD where positive and negative deviations are detected. The best fit model has the lowest AIC score, which is the linear model in this case (from Park and Marwick (2022): Figure 10). |

# Conclusion

# Acknowledgements

# 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, Writing - Review & Editing, Supervision

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

Donghee Chong: Data curation, Review & Editing

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### Colophon

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