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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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Abstract

The transition from the Early to Late Paleolithic in Korea is characterized by the introduction of blade technology, stemmed points, end scrapers, burins, denticulates, and higher proportions of finer grained materials. Stemmed points have been considered a representative tool that led this set of changes. In this study, we examine the possible role that stemmed points played during this technological transition, as well as throughout the Late Paleolithic period (approx. 40~12 ka). Our main questions are as follows: 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 measured tip crosssectional area (TCSA) to distinguish 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 likely served as javelin tips and stabbing spear tips, with smaller numbers as dart tips and un-poisoned arrow tips. TCSA values were controlled mostly by size rather than raw material types. We found different TCSA ranges 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 predominantly produced before the Last Glacial Maximum (LGM). We observed that stemmed points were mostly located in certain ecoregions in Korea, but no clear spatial pattern was apparent. We conclude that stemmed points were multi-functional tools, with many likely designed for use as javelin and stabbing spear tips.

Keywords Late paleolithic \cdot Stemmed points \cdot Blade technology \cdot Tip cross-sectional area (TCSA)

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Introduction

The introduction of new stone artifact technologies marked a major transition in the Korean Paleolithic, from the Early (approx. 350~40 ka) to the Late Paleolithic periods (approx. 40~12 ka). The transition includes blade technology, stemmed points, end scrapers, burins, and denticulates (Bae et al., 2017; Bae, 2017; Lee et al., 2017; Nakazawa and Bae, 2018; Seong and Bae, 2016). Stemmed points are considered to be the first evidence of a suite of new technologies defining the Late Paleolithic period 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 from there, and they have a close association with mobility, site function, 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 (Akoshima and Hong 2018; Lee and Sano 2019). Previous work mostly discussed their origin, the chronology of the Korean Late Paleolithic, and their relationship with the Japanese archipelago (Chang, 2013; Chong, 2021; Park, 2013; Morisaki et al. 2022).

The purpose of this study is to examine the possible uses of stemmed points to understand what role they may have played in the technological transition from the Early to the Late Paleolithic in Korea. We use the tip cross-sectional area (TCSA) metric to infer weapon-use strategies based on comparison with other archaeological and ethnographic assemblages, assuming that different ranges of TCSA values 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 changed over time in Korea around 40~12 ka. Our main questions are as follows: 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 uses? We examine possible links between the roles of stemmed points and environmental change, especially the Last Glacial Maximum, or population dynamics during the Late Paleolithic period. 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 their socio-environmental circumstances.

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 ridges that converge to form an inverted "Y" (Pratt et al., 2020) (Fig. 1). Slight retouch is typically performed on the distal end to shape an acute tip and on the proximal 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 points" to distinguish them from Bronze Age stone projectile points known as "tanged points" in Korea (Park and Marwick, 2022). Understanding the



Fig. 1 Stemmed points from Yongsandong site. 1–6: Plain stemmed points, 7–8: one-sided denticulate stemmed points

appearance of stemmed points is relevant to general questions about the direction of projectile technology, the technological transition into 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. They require two different parts to form one complete tool: a stone point and a shaft, presumably made out of wood (Seong, 2008). Using blades as the blank for the point enables mass production of 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 provides insights into greater cultural, evolutionary, and behavioral cognitive flexibility.

Since the first appearance of stemmed points defines the beginning of the Korean Late Paleolithic, investigating their origins is critical to 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). The debate around the origin of stemmed points can be summarized into two competing models (Bae et al., 2013; Lee, 2016): (1) a "heterogenic" migration (Bae, 2010) and (2) an in situ evolution model (Seong, 2006). 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. The new technology introduced from (1) a Northern route: Siberia, Mongolia, or other regions of northeast China, while the flake tools came through (2) a Southern 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, such as 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 they recognize a few early sites and stemmed points made out of flakes. The in situ model argues that stemmed points appeared before blades, and identifies early sites such as Bonggok, Songamri, Yonghodong, and Hwadaeri as evidence that the Korean Late Paleolithic began with the emergence of stemmed points and gradually transitioned to the blade industry. In contrast, the migration model contends that the Late Paleolithic began with the introduction and widespread use of blade technology similar to the traditional definition of the Late or Upper Paleolithic in Europe and the Later Stone Age in Africa. This model does not classify the stemmed points made out of non-blade materials as authentic stemmed points, thus denying the contiguity of technology (Seong and Bae, 2016). Besides these two main models, there are combination of migration and trade interaction models (Bae and Bae, 2012) and complex and non-directional models (Lee, 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. They found that forager groups using stemmed points may have been associated with the occupation of marginal or extreme environments, in contrast 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 tool size, shape of edge, degrees of damage, and types of edge retouching from the 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 has 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 within Northeast Asia, dating to ca. 41.5 ka, and are made from elongated flakes (Bae et al., 2017; Seong, 2015, 2009). After their first appearance in Korea, stemmed points (Hakuhen-sentoki in Japanese) appeared in Kyushu, Japan, during the late Marine Isotope Stage (MIS) 3 (Abe 2005; Kizaki 1994; Morisaki et al. 2022). In addition to the stemmed points, there are similar artifacts found in both regions, such as microblade cores, Moppule-seokgi (Kakusuijo-sekki in Japanese),

backed knives, bilateral points, bifacial points, and transport of obsidian (Chang, 2013; Kim and Chang, 2021; Lee, 2015, 2012; Morisaki et al. 2022).

Previous Studies About the Function of Stemmed Points

Though stemmed points have generally been assumed to have been hunting armatures (Chang, 2013; Lee and Sano, 2019; Lee and Jang, 2011; Lee and Kong, 2002; Seong, 2008), it has been difficult to determine their likely uses without knowing their complete shape when attached to other components. Preserved wooden components of prehistoric projectile tools are too few and rare to standardize their overall scale and variability (Shea, 2006). Lee and Kong (2002) claim stemmed points should be considered more generally as "stemmed tools" because of the uncertainty of their complete shape. Other researchers propose that non-symmetrical stemmed points — with retouch on one side or denticulate blades on one side — should not be referred to as stemmed points but rather as stemmed knives, stemmed side-scrapers, stemmed end-scrapers, or stemmed burins (Fig. 1: 7–8) (Kim, 2017; Lee and Jang, 2011; Seong, 2008).

Stemmed points are typically symmetrical from tip to tang, with the central axis serving as a line of symmetry (Lee and Jang, 2011). There is a high percentage of broken tips and stems, and the reused tools were repaired in accordance with 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). For example, at Yongsandong site, only 10% of the tools are complete, while 33% of the tips are missing. In the case of Jingeuneul, the percentages are 16% and 50%, respectively (Park, 2013). Beyond the examination of the morphological aspect of stemmed points, investigations of a whole site and the tool composition of an assemblage suggest 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).

In recent years, use-wear analysis has been applied to understand the functions of stemmed points. Akoshima and Hong (2018) conducted a study using 96 stemmed points from the Suyanggae site (Locality VI and I). They examined microflaking and microwear polish to identify which parts of the stemmed points were used, the types of motions applied, and the materials with which they were used. Their findings show that stemmed points might not be exclusively projectile weapons. Instead, the results support a versatile range of applications, including cutting, sawing, scraping, and whittling. Lee and Sano also (2019) conducted use-wear analysis on 95 stemmed points from Jingeuneul site. Based on their results, a substantial number of the stemmed points exhibited diagnostic impact fractures (DIFs) on the surface. These fractures were most likely the results of longitudinal forces from the shaft, suggesting a plausible mechanical propulsion method, such as a spearthrower or a bow.

Tip Cross-sectional Area

The tip cross-sectional area (TCSA) of stone artifacts has been used as a ballistically relevant standard to probabilistically discriminate between likely weapon-tip types, such as spear-thrower (a.k.a. atlatl) dart tips, un-poisoned arrow tips, and large stabbing/thrusting spears (Lombard, 2020, 2021, 2022; Lombard et al., 2022; Lombard and Moncel, 2023; Lombard and Shea, 2021; Metz et al., 2023; O'Driscoll and Thompson, 2018; Sisk and Shea, 2011). It is critical 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 is related to weapon flight and penetration dynamics (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). This method was first proposed by Hughes (1998) and validated by Shea (2006) through the comparison of archaeological examples with ethnographically collected samples of known use. Lombard et al. demonstrated the efficacy of TCSA by analyzing Middle Stone Age points from Sibudu Cave in KwaZulu-Natal, South Africa, which are dated to approximately >60 ka. They compared the results obtained from experimental and use-trace studies such as organic residue analysis, macrofracture analysis, and use-wear analysis with TCSA values (Lombard 2004, 2005, 2020, 2021). Shea (2009) also applied the approach to compare projectile points from Africa, the Levant, and Europe, claiming that projectile weapons first appeared in Africa.

One of the key advantages of the TCSA metric is its convenience of application: regardless of the point type, only the maximum width and thickness measurements are required to calculate the TCSA value (0.5 × maximum width × maximum thickness) (Lombard, 2020; Sisk and Shea, 2011). Later, Sisk and Shea (2011) proposed an alternate metric, tip cross-sectional perimeter (TCSP), for a more precise measure of the force required to penetrate a target to a lethal depth, whereas the TCSA metric is more associated with cutting. 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 the southwest of Korea, which has the largest number of stemmed points (n = 99) found at a single site to date. For the TCSA, they were only able to use ten stemmed points since they selected stemmed points that retained the widest and thickest parts of the specimens and showed diagnostic impact fractures for the use-wear analysis. Their purpose in using TCSA was to compare the values to North American dart tips and arrowheads. Their results show that the range of TCSA values for Jingeuneul stemmed points is relatively wide, overlapping with both North American dart tips and arrowheads. Along with the results of use-wear analysis, 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 a much larger sample of stemmed points from all over South Korea to better understand their likely uses during the Late Paleolithic.

Methods

Archaeological Sites

After the first discovery at the Seokjangri site in the 1960s, more than 450 stemmed points have been found at 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 retained their widest and thickest parts. We excluded broken artifacts that lacked the widest and thickest parts, but included those with minor tip damages where we could clearly discern that the maximum width and thickness were present. Our dataset also contains stemmed points discovered during field surveys as well as those found at sites that were never dated but were associated with other Late Paleolithic 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 (Fig. 2). 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 taken place 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 from the four by using a different site name, Hajinri, following the convention established by the excavators at that location. Hajinri is the sixth excavation location at Suyanggae, which is 3.5 km apart from the other areas and dated 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 blades 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 (around 41.5 ka) in our collection as the first appearance of stemmed points.



Fig. 2 Korean Paleolithic sites mentioned in this study

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 for stemmed points, we calculated TCSA values for the stemmed points in our sample. We also explored the interaction of TCSA values with raw materials and artifact size, using weight

as a proxy. Because the shape of stone artifacts is highly influenced by the raw materials (McPherron et al., 2014), we assumed that raw materials may be highly correlated with tool size. We investigated radiocarbon ages associated with the points in order to determine temporal patterns in TCSA values. We separated the research time period into three phases, based on the major climate event during the Late Pleistocene, the Last Glacial Maximum (LGM). Previous research on the LGM climate in Korea, using age-controlled pollen records (Yi and Kim, 2010) and computational simulation models (Kim et al., 2015; Park and Marwick, 2022), indicates that the climate was colder and drier than the preceding period. Surface temperature cooling ranged from 5 to 6°C, and there was a precipitation decrease of approximately 14%. Using this chronology, we examined the distribution of TCSA values before, during, and after the LGM. We then explored the relationship between TCSA values arcoss ecological and vegetation zones.

To aid in interpreting our results, we referenced the TCSA ranges for different weapon-delivery systems that Lombard et al. (2022) and Lombard (2021) created by summarizing the analysis by Wadley and Mohapi (2008) of backed microliths (Table 1). We excluded 12 artifacts from our dataset with TCSA greater than 250, which were outside of the range of our comparative data. For this comparison with weapon-delivery systems, we included TCSA values from a total of 161 stemmed points from 33 assemblages unearthed from 25 sites.

Raw Materials

Selective use of raw materials 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 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."

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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

Table 1 TCSA ranges from Lombard et al. (2022)

Weight

Different sizes of stone artifacts can constrain or enable different functions. Overall size of stone points has been used as a potential proxy for identifying different types of armatures (Sahle and Brooks, 2019; Thomas, 1978). We chose weight as a proxy for the overall size of the stemmed points. As a reliable discriminator between tools of different sizes as well as a descriptive attribute, weight can be measured rapidly and objectively (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 directly measure or obtain records of their weight, we explored the relationship between TCSA and weight for 152 artifacts.

Temporal Patterns

We used radiocarbon ages to investigate the temporal patterns of the likely uses of stemmed points. After excluding assemblages that have no radiocarbon dates, we used 26 assemblages dated from 45 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 analyze spatial patterns in TCSA values. Among the 25 sites, we combined those that contained fewer than five stemmed points and named them "Other." We explored the 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 the distributions across four vegetation zones and 16 zones that differed in terms of their geographical characteristics.

The vegetation zones are based on Yi and Kim's (2010) classification 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's (1975) forest vegetation map, defined by recent temperature and precipitation values.

We also explored spatial patterns using 16 geographical zones based on geographical characteristics including inland, coastal areas, major rivers, islands, 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). Then, we used longitude and latitude to locate individual assemblages and examined TCSA values for each zone. We note that modern eco-regional maps may not fully resemble the Pleistocene landscape in which the points were made and used. Unfortunately, reconstructions of Pleistocene landscapes are not available for our study area. We assume the underlying environmental factors such as altitude, slope, drainage, hydrology, and bedrock are relatively stable over time, and are suitable as an analogy for initial hypothesizing about relationships between Pleistocene geographical variation and stone artifact technology.

Modelling Weapon-Tip Type Selection

The process of introducing novel technologies can vary based on the social and environmental context in which the transmission of manufacturing techniques for the new tools takes place. Furthermore, the new tools themselves can alter the typical contexts of tool use. In America, for example, the advent of bows and arrows provided non-elite hunters with the opportunity to produce their own subsistence or pursue individual wealth without the necessity of hunting in teams (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 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. In one example, Eren et al. (2022) compared 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 landscapes. Clovis points were used as multifunctional tools that performed a wider range of tasks, including cutting and sawing. On the other hand, Folsom points show a narrower range of variation, indicating they were more likely used for a small set of specific tasks.

Inspired by Eren et al. (2022)'s approach, we hypothesized 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 the tools were being used as part of an adaptation to moving into unfamiliar landscapes, with unpredictable variations in patch productivity and travel times. The variability of TCSA values, as measured by coefficients of variation (CV), in the LGM is predicted to increase as lower temperatures alter the distribution of resources and reduce the predictability of resource encounters. After the LGM, we anticipate a reduction in the range of TCSA values, with higher temperatures and increased bioproductivity.

In response to heterogeneously distributed food resources, TCSA values are predicted to vary across vegetation types and geographical zones. In harsh environments with lower patch productivity, similar to the case of the LGM duration, we expect to observe a further increase in the variability of TCSA values. On the other hand, 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. Therefore, our prediction is that the range of TCSA values will be narrower in coastal areas such as vegetation zones ST and SW and geographical zone ESC, compared to inland areas such as vegetation zone CT and geographical zone CI.

The entire R code (R Core Team, 2021) and data files used for all the analyses and visualizations contained in this paper are 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, and statistical test results presented here 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 the figures as CC-BY, to enable maximum re-use.

Results

TCSA Range of Korean Stemmed Points

Figure 3 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 in TCSA values. The sample mean of TCSA is 95.5, and the standard deviation of TCSA is 44.1. According to the TCSA ranges presented in Table 1, Korean stemmed points are mostly found 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.

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, revealing three clusters of artifact sizes (A of Fig. 4, mean = 10.1, SD = 7.3). Cluster 1, the smallest (lightest) artifacts, has a lower range of TCSA values



Fig. 3 Distribution of TCSA values for all Korean stemmed points in the current dataset. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 1



Fig. 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. Numbers represent each cluster. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 1

compared to cluster 2 (B of Fig. 4, mean = 94.5, SD = 42.8). TCSA values for cluster 3 are the highest, except for one artifact, which is lower than 50.

Variation in TCSA Values by Raw Material

Figure 5 shows that about half of the stemmed points were made from shale and its TCSA range is widely distributed. The TCSA values of acidic volcanic rocks are



Fig. 5 TCSA values by lithic raw material. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 1

commonly skewed lower. Other raw materials, including hornfels, rhyolite, and tuff, show a wide distribution, similar to shale. The category of "Other" raw materials includes porphyry, trachyte, felsite, chert, quartz, quartzite, granite, mudstone, and unidentified rocks. Overall, there is no clear pattern of TCSA values among different raw materials (F(5, 154) = 2.72, p = .022).



Fig. 6 Artifact size and TCSA values by lithic raw material

Figure 6 shows positive relationships between TCSA for 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 Fig. 5).

Temporal Patterns of TCSA Values

Figure 7 shows 26 assemblages with stemmed points in chronological order (panel A). These assemblages have a wide range of TCSA values, indicating multiple likely



Fig.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. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 1

uses for stemmed points. Overall, there is no clear pattern in these assemblages over time. The TCSA range varies depending on the assemblage.

To explore the impact of climate change on the likely uses of the artifacts, panel B of Fig. 7 shows the distribution of TCSA values from assemblages aggregated into three periods: before, during, and after the LGM. Our results show that stemmed points were made predominantly before LGM and only a few after LGM. Each category shows wide variation in LGM, which indicates diverse uses of stemmed points. While the median TCSA 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).

Spatial Patterns of TCSA Values

We computed artifact TCSA values for 25 sites that contain more than five stemmed points to observe variation between sites (F(6, 154) = 3.29, p = .004) (Fig. 8). Sites with fewer than five 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 the Suyanggae site. Nosanri, Sibuk, and Wolpy-eng have a narrower range of lower values, which indicates less diverse likely uses for stemmed points. Yongsujaeul shows a narrower range but higher TCSA values. Yongsandong has the second highest number of stemmed points and shows two clusters of TCSA values.



Fig. 8 TCSA values by archaeological site. The shaded boxes in color indicate TCSA ranges for different weapon types based on Table 1

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 the vegetation map and Central inland (CI) (Fig. 9 panels A and D) of the eco-region map. We observed some statistically significant differences in the distribution 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) are significantly different from the other two vegetation zones (Fig. 9 panel C). Looking into this further, we see that there are only six artifacts from the



Fig. 9 TCSA values by assemblages and ecoregions. A Modern vegetation map defined by temperature and precipitation. The individual points indicate assemblages. B TCSA distribution for vegetation zones. The individual points indicate artifacts. C Tukey test result for vegetation zones. D Eco-region map based on geographical boundaries and ecological conditions (modified from Lee et al. (2008)). E TCSA distribution for ecoregion zones, excluding zones with no artifacts. F Tukey test result for eco-region zones

ST zone, with only three of these having TCSA values above 175. The other three have TCSA values lower than 100, similar to the other zones (Fig. 9 panel B). Given the small number of artifacts with extreme TCSA values in the ST zone, we hesitate to conclude that 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; this was likely due to the small number of points in several zones (Fig. 9 panel F). Overall, our results indicate no clear patterns in the distribution of TCSA values across vegetation and eco-regional zones.

Discussion

By comparing the results with the TCSA ranges from other archaeological and ethnographic cases (Table 1), we were able to examine what role stemmed points played in the technological transition during the Korean Late Paleolithic. Our main questions were as follows: What were the best-fit ballistic probabilities for 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 uses?

Our results indicate 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 fall within the ranges of dart tips and un-poisoned arrow tips. None has TCSA values in the range of poison arrow tips (Fig. 3). In their study, Lee and Sano (2019) calculated TCSA values for ten stemmed points with DIFs from Jingeuneul site, which were not included in this research due to the unavailability of their data. They claimed that these values are within the range of North American dart tips and arrowheads. We found a wider range of TCSA in our sample covering the range of dart tips and un-poisoned arrow tips, which are assumed to be equivalent to arrowheads. In general, the wide range of TCSA suggests that stemmed points may have had diverse roles within foraging toolkits. Akoshima and Hong's use-wear analysis (2018) claims stemmed points had multiple uses rather than hunting-specific purposes. The wide range of TCSA values in our results is consistent with this interpretation of diverse functions for stemmed points.

TCSA can be impacted by other factors such as raw materials and portability. Eren et al. (2022) explain that lower TCSA values could be the result of pursuing production economy and transport efficiency. We explored the relationship between TCSA for weight and raw material types in order to examine these factors. We found that different clusters of weight are matched with different types of weapon tips (Fig. 4). There was no clear pattern for raw materials (Fig. 5). However, combined with weight, we observed a positive relationship between raw material type and TCSA values (Fig. 6). We speculate that this might be due to the higher availability of raw materials, such as shale and hornfels within the landscape. Therefore, we find that raw materials, via nodule size, were influential on TCSA values.

Our results show that TCSA values vary between assemblages with few discernible temporal patterns in function (Fig. 7 panel A). Contrary to our prediction, the earliest stemmed points do not have more variable TSCA values than subsequent ones. The most striking temporal pattern is simply that stemmed points were produced and discarded most frequently before the LGM (Fig. 7 panel B). While we predicted the greatest variation in TCSA values during the LGM, our results show the opposite: variability decreased during the LGM (CV = 38.08), in comparison to the previous period (CV = 44.87). This could be explained by the overall decline in stemmed point usage, perhaps due to a retreat into refugia during the LGM, rather than increased mobility into unfamiliar areas.

We found that stemmed points are primarily located in a small number of eco-regional zones such as the Central Temperature (CT) Zone with few clear patterns in TCSA function evident across the zones (Fig. 9). As predicted, TCSA values in inland areas, such as the CT Zone, show higher variability. These results suggest that stemmed points performed a wider range of tasks in low-productivity patches. Prates et al. (2022) claimed that fishtail projectile points in South America were used to hunt megafauna and contributed to their extinction by demonstrating a strong correlation between the spatial and temporal distribution of megafauna and the projectile points. We similarly found that stemmed points are more densely distributed in certain environments in South Korea. Future work should investigate more specifically patterns in the distribution of stemmed points and ranges of faunal taxa.

Overall, our results show a wide range of TCSA values throughout the Late Paleolithic period and between eco-regional zones. The widest TCSA range was found at a single site, Suyanggae (Fig. 8). Our findings are therefore consistent with our second scenario, in which stemmed points are best described as multifunctional tools, suggesting that in most cases, people created stemmed points as a response to unexpected or varying circumstances in their specific habitats, similar to how Eren et al. (2022) explained Clovis points. The LGM period may be the exception here, with a reduction in variability during this time.

Conclusion

Considering the importance of stemmed points for the technological transition during the Late Paleolithic in Korea, our research examines the likely uses for 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 were 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., maximum width and thickness) to compute the metric. We calculated TCSA for a total of 161 stemmed points from 33 assemblages excavated from 25 sites. Then we examined the TCSA values with other variables, including raw materials, weight, radiocarbon dates, and site locations. Drawing on evolutionary theory, we premised that the uses of stemmed points likely reflect the socio-environmental circumstances that people encountered. We examined the possible impact of the LGM on stemmed points and their distribution across eco-regional zones.

According to the different weapon-delivery systems that can be inferred from TCSA values, the majority of stemmed points from the Korean Paleolithic were probably used as javelin tips and stabbing spear tips. In general, though, we noted a wide range and also differing distributions of TCSA values in each assemblage. Therefore, we conclude that stemmed points served diverse and not highly patterned roles during the Late Paleolithic. Prior to the LGM, people may have encountered unfamiliar situations and use stemmed points as a multifunctional tool to carry out multiple tasks. During the LGM and following we find production and discard of stemmed points declined, but their ballistic properties remained largely unchanged. Considering that many of our predictions about TCSA were not supported by the data, we speculate that composite projectile points made with microblades were introduced (Chang, 2013) in response to global climate dynamics, and stemmed points were optimal for the wide range of conditions encountered by people during the Late Paleolithic in Korea.

We are aware that discriminating the likely use of small numbers of projectile points could be arbitrary (Erlandson et al., 2014). Since TCSA covers the critical elements of projectiles, flight, and penetration dynamics (i.e., increase or decrease by shape of tip and cross section), we nevertheless consider it a useful metric for hypothesizing about different weapon-delivery systems (Hughes, 1998; Lombard, 2021; Sitton et al., 2020). Use-wear analyses and experiments should be part of future research into the function of stemmed points to investigate the validity of our current results.

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Author Contribution Gayoung Park: software, validation, formal analysis, resources, data curation, writing — original draft, writing — review and editing, visualization, project administration

Marlize Lombard: conceptualization, methodology, supervision

Donghee Chong: data curation

Ben Marwick: software, validation, formal analysis, investigation, writing — review and editing, visualization, supervision

Data Availability The raw data, R code for data analysis and visualization, figures, and tables for this paper are openly available at https://doi.org/10.17605/osf.io/dqna8 to enable re-use of materials and improve reproducibility and transparency.

Declarations

Ethical Approval Not applicable.

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