Numeration Systems on the Admiralty Islands

and Implications for the Mental Number Line

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Abstract

Over the last decades there has been growing interest in the relationship between cognition and culture. One question that has yet to be answered on this topic is the role counting systems have for cognition. Counting systems vary between cultures and may influence the mental representation of numbers. On that note, some authors argue that numbers map onto a mental number line that is used when dealing with numbers. This thesis gives an overview of numerals for the Admiralty Islands, an Island group located outside of Papua New Guinea. It analyzed the counting systems and their implications for the mental number line. The aim of the study was to investigate the characteristics of number systems on the Admiralty Islands in order to investigate how these characteristics may affect the mental number line. The thesis took an explorative and theoretical method approach where numerical data on the languages of the Admiralty Languages were gathered from literature. The results from the data collection suggested that the counting systems on the Admiralty Islands facilitat a linear, two- dimensional mental number line ranging from 1 to 100. It was concluded that various cultural aspects could be influential in shaping the mental number line. The predictions made may be used as a basis for further empirical research on mental representations of numbers.

Keywords: numerical cognition, numeration systems, number representations, mental number line, Admiralty Islands, number processing

Sammendrag

Over de siste tiårene har det vært økende interesse for forholdet mellom kognisjon og kulturelle innflytelser. Et spørsmål som ikke er besvart er tallsystemers påvirkning på kognisjon. Tallsystemer varierer mellom kulturer og kan påvirke den mentale representasjonen av tall. Noen forskere argumenterer at tall blir representert på en mental tallinje (mental number line) som blir brukt når man håndterer tall. Studie for hånd analyserte tallsystemer på Admiralitetsøyene og deres implikasjoner for en mental tallinje. Målsettingen var å undersøke ulike trekk av tallsystemene på Admiralitetsøyene, for å belyse hvordan disse tallsystemene kan påvirke den mentale tallinjen. Studien brukte en teoretisk metode der data om tallsystemer på Admiralitetsøyene var samlet inn fra ulik litteratur. Resultatene av innsamlingen indikerte at tallsystemene på Admiralitetsøyene fremmer en lineær, to-dimensjonal mental tallinje som strekker seg fra 1 til 100. Det ble konkludert at ulike kulturelle sider var påvirkningsdyktig på en mental tallinje. Studiens prediksjoner kan bli brukt til videre empiriske studier på mentale representasjoner av tall.

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Introduction

Over the past three decades there has been a growing interest in culture and how cultural practices influences mental processes (Brysbaert, 2018). An interesting area of debate on this matter regards numerical cognition, which is the study of different factors that underlie numerical abilities. Two examples of numerical abilities are memorization - and the manipulation of numbers (Knops, 2020, p. 1).

Several factors may underlie numerical abilities. On that note, both linguistic - and embodied (i.e., bodily experiences) theories for numerical cognition have been proposed to promote the development of numerical abilities. Some linguistic theories put forward that numerical skills are based on knowledge learned in language acquisition. For instance, when aquiring a language it is learned how letters and words are structured in grammatical systems to produce sentences (Dehaene 1992; Dehaene et al., 1998). This knowledge may also be valuable for development of number skills. Instead of the manipulation of words and letters according to grammatical systems, numerical abilities involve manipulation of numbers according to formulas. Due to such similarities, one might promote the other (Brybaert, 2018, p. 8). Other linguistic theories highlight the role of number semantics, which are the different meanings we assign to numerals. Indeed, numbers can be used in different ways depending on what they are wished to represent (Bylinina & Nouwen, 2020). It may be unintuitive to think of numbers as varying in meaning due to the rigidness that has been ascribed to mathematics, and thus also to numbers. However, studies demonstrate that number semantics can be culturally bound and thus vary. To illustrate, the meaning of “twelve” could be changed by adding word determiners such as *every*, *some*, *several* or *most.* “Some twelve people came to the party” indicate that any number of participants around twelve attended the party; whilst “at most twelve people came to the party” indicates that not more, rather less, than twelve people attended. Other ways to manipulate the meanings of numbers is to use *first*, *second* and *third* to indicate order, to use adverbials like *twice* to indicate number of times, and the use of percentages and fractions such as *twenty percent* and *one fifth* to indicate proportion (Bylinina & Nouwen, 2020).

Embodied theories for numerical skills come from a different perspective. They propose that that bodily experiences are encoded in numerical representations (i.e., the mental organization and storage of number knowledge; Thompson et al., 2013). To explain this point further, it is beneficial to review studies on the mental number line. Pioneering work from Dehaene (1992) suggested that there is a specific mental quantity system for representations of numbers up to 4. Furthermore, that there is an approximate mental quantity system for numbers larger than 4. Together, they might generate what has been termed the mental number line (MNL) (Dehaene & Changeux, 1993). The MNL has been described as a horizontal line on which numbers are placed. This line is used for any mathematical operation such as for subtraction and addition of numbers, which enables quick calculation times and lessens the cognitive workload. The start, - and endpoint of the line is dependent on which numbers are being processed. To exemplify, if the task is to add 5 to 51, one might have a line that starts at 51; then add 1 five times to get to 56. Or one may have a line that starts with 50, as round numbers are easier to calculate with, and add 5 in one big ´jump´ and another 1 for the earlier subtraction to get 56 (Schiller et al., 2016). Embodied theories suggest that bodily experiences may be important for the development of the MNL. For instance, one study showed that the processing of *basement–attic* in participants was faster when presented vertically. They argue that these results are based in embodied experiences of going *up* to the attic and *down* to the basement (Louwerse, 2008). Such bodily experiences will perhaps affect the MNL in a similar way. For example, some researchers propose that the MNL is affected by reading direction (Shaki et al., 2012; Shaki & Fischer, 2012). The MNL in cultures where reading direction is from left to right follows the same direction, with smaller numbers represented on the left side of the line and larger numbers represented on the right side of the line. The opposite observations have been made for cultures where the reading direction goes from right to left. Thus, culture is potentially important for the MNL. Although it should be noted that there is evidence that a MNL may exist before the onset of cultural influences (e.g., Di Giorgio et al., 2019; Ebersbach et al., 2014).

Taking culture specific ways of number representations into account is important for at least two reasons. First, general numerical knowledge is valuable as numerals are central in everyday life. Numbers are used in language for expressing quantities such as “two kilos of apples”, for labeling bus lines and trains, to communicate with each other through assigned telephone numbers, keeping track of payments and much more (Rothstein, 2017, p. 2). Secondly, cross-cultural studies are significant for broadening the scope of numerical cognition as number tools vary greatly between cultures. As a result of missing cultural diversity, information may be neglected which leads to a potentially incomplete picture of numerical cognition. Due to both earlier colonialism and globalization, languages are disappearing and language-coded cultural information is becoming scarce (Bender & Beller, 2011). For that reason, numerical information from minority cultures, such as the Admiralty Islands, is particularly of essence.

Despite a growing interest in the relationships between numerical cognition and culture, many questions are yet to be answered. For instance, how different counting practices map onto the MNL (Bender & Beller, 2011). The present research attempts to answer this question, by a conceptual analysis of the counting systems on the Admiralty Islands and of their cognitive implications. The aim is to investigate different cross-cultural factors that may have implications for mental representations of numbers. Based on a review of previous research, it is predicted that both linguistic and embodied numeracy factors will impact the MNL. The most prominent of these factors will be discussed in the following study, along with potential alternative explanations of the observed effects that are used as evidence to support an MNL account. Specifically, specific characteristics of the MNL will be reviewed along with cultural and embodied influences that may promote these characteristics in the first part of the study. Counting systems of the Admiralty Islands will be introduced in the second part of the study, after which a discussion on possible implications on the MNL will follow.

The Mental Number Line

The MNL is, as stated, described as a line on which numbers are placed and for which judgement and calculation of numbers is used (Schiller et al., 2016). The majority of research has established that the line is horizontal, that it follows the direction from left to right in cultures where the reading direction is from left to right, and that it is associated to space (Bender et al., 2018). The latter point specifies that the MNL hypothesis is grounded in number–space associations. Consideration of the senses are central to further elaborate this point. The senses connect the mind to the outside world as information gatherers. As such, the world is experienced through the senses. When extending this mode of thought, it can be assumed that mental representations of numbers are affected by sensory experiences that contain spatial information. Numerous such experiences are present in the modern world. For example, numbers are presented on classroom blackboards and on computer keyboards (Fias et al., 2011, p. 138; Cooney et al., 2021).

Characteristics of the Mental Number Line

Having established the general assumptions of the MNL, more detailed characteristics will be reviewed. In given order, dimensions, range and scale of the MNL will be discussed. Dimensions are interesting in terms of possible axes of the MNL; range is important in terms of the extent of the MNL; and scale is of interest for the representation of numbers on the MNL.

Dimensions. Initial research stated that the MNL is represented as a horizontal axis (Dehaene, 1992). However, later study results suggest that representations may also take place on two other axes, one vertical and one sagittal. This gives the potential for a three–dimensional MNL. A horizontal axis represents numbers in a dimension of left to right, a vertical axis represents numbers in a dimension of up or down, and a sagittal axis represents numbers in a dimension of close and far (Aleotti et al., 2020).

The Spatial–Numerical Association of Response Codes effect (SNARC) has been argued as evidence for a horizontal MNL. A brief specification of the SNARC effect is provided at this point of the thesis for the purpose of examining dimensional evidence, although a more comprehensive description is given later. The SNARC effect is present when the reaction time to small numbers is shorter when presented with left–sided stimuli, as compared to when presented with right–sided stimuli; and reaction time to large numbers is shorter when presented with right–sided stimuli, as compared to when presented with left–sided stimuli (Dehaene et al., 1993). To illustrate, in a magnitude task participants can be asked to indicate which of two numbers is smaller by pressing a button either with the left hand or the right hand. There is a tendency of shorter reaction time to smaller numbers when visually presented on the left in combination with pressing the left-hand button. Moreover, there is a tendency of shorter reaction time to larger numbers when visually presented on the right in combination with pressing the right-hand button. The effect could indicate that left–side responses are related to small magnitudes, and right–side responses to large magnitudes; consequently giving a horizontal MNL (Cooney et al., 2021). The SNARC effect is seemingly robust as it has been found under varied experimental conditions such as head direction (Pasqualotto et al., 2014) and bodily position (Hartmann et al., 2012) as well as within varied age groups (e.g., Hoffmann et al., 2013; Gibson & Maurer, 2016). A horizontal MNL may stem from external situations where numbers are arranged from left to right. Graphs, rulers, measuring tapes and timelines are examples of influencers that may promote the development of a mental horizontal axis (Winter et al., 2015). Moreover, finger counting in western countries usually start from the left hand, which could be another contributing factor (Pitt & Casasanto, 2014, pp. 1174-1179).

The SNARC effect has also been interpreted by researchers as evidence for a vertical MNL axis (e.g., Cooney et al., 2021). For example, when physically being elevated participants tended to generate larger numbers. And when physically being lowered participants tended to generate smaller numbers (Hartmann et al., 2012). Similar findings are reported for head direction (Winter & Matlock, 2013, pp. 3789–3974) and in magnitude tasks (Cooney et al., 2021; Aleotti et al., 2020). Explanations for the results vertical axis are similar as those arguing for a horizontal axis. A vertical axis may, like to a horizontal axis, stem from external situations where numbers are represented in an identical manner as the mental axis. Thermometers, growth, rising prices, height and battery power are examples of external factors that may promote the development of a mental vertical axis (Cooney et al., 2021). Additionally, numbers are linguistically referred to as *low* and *high*, which could contribute to a magnitude representation of numbers (Lakoff & Johnson, 1980). Building on the study example given above, changing the physical position of participants implied not only a vertical axis but an additional sagittal axis. When physically moved backward participants tended to generate smaller numbers, and when physically being moved forward participants tended to generate larger numbers (Hartmann et al., 2012). Similar findings are reported in magnitude tasks (Cooney et al., 2021; Aleotti et al., 2020). A sagittal MNL may stem from the heuristic of perceiving large numbers as *more* and believing that *more* is spatially further away. If so, small magnitudes may be attributed to near space and large magnitudes to far space, giving the observed SNARC effects (Winter et al., 2015).

In sum, there is evidence suggesting that the MNL can have three dimensions consisting of a horizontal axis, a vertical axis and a sagittal axis. However, few studies accounting for all three dimensions have been completed. An associated question is whether one axis is dominant above the others. Results are also inconsistent on this matter. Some hypothesize that the axes can be activated separately dependent on what the situation calls for. A vertical axis may be dominant when judging the height of a building, and a horizontal axis when judging length. Such flexibility may have been especially important for earlier survival. Estimating how far away an animal is, could have been advantageous for catching prey; knowing how deep the water is, could have been essential for fishing; and judgement of how tall a tree is, could have been important for fetching eggs (Simms et al., 2013).

Range. The range of number representation will perhaps vary between numeral systems. Some claim that the represented numbers are those which are most frequently used, those who do not have complex and long names, as well as those who are smaller in magnitude rather than high in magnitude. Therefore, it is predicted that for most numeral systems the numbers 1 to 99 are present, although digressions may occur (Brysbaert, 1995). For example, it has been argued that the onset of the MNL is 0 rather than 1. Using an automatic monitoring task, it was indicated that 0 was the smallest represented number. Automatic monitoring is happening when number representations are activated and when this activation do not occur due to task requirements. The use of this method is predicted to show numeral values held in long–time memory, argued to be the “building blocks” of the MNL (Pinhas & Tzelgov, 2012).

A related discussion point is whether negative numbers are present on the MNL. This discussion is led by three theories. *A holistic theory of number representation* claims that negative numbers are represented on the left–side space of an MNL. According to this theory, the components of the number (e.g., “-“ and “9”) are seen as one whole (i.e., “-9”). In opposition is the *components theory of number representation*, which claims that only positive numbers are represented mentally. According to this theory, negative numbers are generated from positive ones. In that way, a negative number is regarded as a component of a positive number plus that of a negative indication sign (i.e., "-" and "9"). Lastly, *a context–dependent theory of number representation* states that dependent on the situation a holistic or components representation of numbers is employed. Support is found for all theories. For instance, in an eye–tracking study it was observed that participants employed a holistic approach when presented with positive and negative numbers. However, when presented only negative numbers the participants were observed to employ a components approach (Zhang & You, 2012; Fischer & Shaki, 2017). Furthermore, there are also disagreeing studies who failed to find an indication of mental representation of negative numbers (Ganor-Stern, 2012).

Some notes on decimals and fractions will be discussed as a last point regarding range. Evidence on whether these are represented on the MNL is inconclusive (DeWolf et al., 2014). Some research has shown that fractions as well as decimals are regarded as integers, thus suggesting a holistic representation. However, the results suggested a components representation for negative numbers, indicating that they are not mentally represented as whole numbers (Ganor–Stern, 2012). These results are interesting because similarly to negative numbers, decimals and fractions contain assorted components. Thus, it could be assumed that their exclusion or inclusion on an MNL would be in agreement. A follow up study showed that equally as fractions, decimals had a holistic representation (Ganor–Stern, 2012). Such results have been supported by other studies (e.g., DeWolf et al., 2014). On the one hand, it can be argued that a decimal and a fraction can hold the same magnitude and thus should be equally represented (e.g., 0.5 and 1/2). On the other hand, they are differently structured and may therefore be cognitively represented unequally. A fraction is bipartite, consisting of a numerator and a denominator separated by a mid–line. A decimal, however, is made up by whole numbers and the value is dependent on placement of a separating comma. Some indications of discrimination between fractions and decimals have been shown in adults. However, it has been more difficult to detect in children (DeWolf et al., 2014). This could be due to a limitation of number knowledge in children. To illustrate, children tend to believe that the more components a number hosts, the bigger the magnitude is (i.e., 4.52 is judged as bigger than 5). Moreover, since decimals are made up of integers, wrongful attributes may be transferred and applied (Ganor–Stern, 2013; Rittle–Johnson et al., 2001). Decimal and fraction number knowledge develop on the MNL along with formal schooling.

Scale. As noted by some authors, the MNL may not take the shape of a prototypical line. As suggested by evidence, it may have logarithmic features. Therefore, the possibility of non–linear curves and patterns should not be disregarded (Bender & Beller, 2011). On that note, there are different theories arguing for the scale of number representations. The log–Gaussian model assumes that numbers are represented on a logarithmic line. Since the line is logarithmic, the intervals between represented numbers differ. The MNL hypothesis is in line with the log–Gaussian model, as it assumes that high numbers are more compressed than low numbers (Dehaene, 2007, pp. 527-574). In contrast to the log–Gaussian model, the scalar variability model which assumes that numbers are arranged on a linear scale with equal number intervals (Gallistel & Gelman, 2000). Whilst their prediction of number calculation is relatively similar, they differ at some points. For instance, when assuming a compressed scale for high numerals, then the average distance between a set of numbers should be higher than the real average. If one assumes a linear scale where the intervals are fixed, the estimated average between a set of numbers should be closer to the true average. However, both models assume that higher numerals are harder to judge and discriminate, so neither theory would predict that the true average would match the estimation. A study using the described method found that half of the participants used a linear scale when estimating the average and the other half used a slightly logarithmic scale (Katzin et al., 2020).

Perhaps the question is not whether the scale is either linear or logarithmic but rather how it develops. On that note, evidence has suggested that children have a logarithmic numerical scale while adults have a linear numerical scale, suggesting an age dependent MNL. Formal schooling may be a reason for this change. The numerical knowledge in children is limited, especially for high numbers. Thus, as the knowledge and familiarity with numbers increases, one could predict that the MNL takes on a more linear scale (Berteletti et al., 2010). Findings of a logarithmic number scale in adults have been found, which stands in disagreement to this theory (e.g., Katzin et al., 2021). Nevertheless, the idea of both linear scale use and logarithmic scale use by the same individual is intriguing and has been supported by other studies (e.g., Anobile et al, 2012). For instance, experiments indicated that a logarithmic scale was used initially when calculating, shortly before a linear scale replaced it. Taken together with the notion of an age dependent MNL, the most natural and biological approach may be to use a logarithmic scale, and only when other formal approaches are applied a linear scale will take over (Dotan & Dehaene, 2013). Taken together, studies support both the notion of a linear scale and a logarithmic scale. Moreover, both scales may be present at the same time.

Moving on from the general characteristics of the MNL, some evidence supporting the claim that the MNL is shaped by experiences will be given. Specifically, reading, writing, and body-based counting will be discussed as cultural influencers of the MNL. Additionally, the relevance of embodied cognition in the development of an MNL will be highlighted.

Influences from Culture and Embodied Experiences

The MNL theory is based on that mental representations of numbers are formed through space–number associations (Fias et al., 2011, p. 138). Some researchers argue that visuospatial experiences are needed in order to form such associations. These are situations that involve an external, spatial and visual organization of numbers. As mentioned, mathematical rulers are examples of tools that spatialize numbers. Although rulers are used as a tool for measuring in many cultures, their structures are culturally dependent. To illustrate, rulers in the United States are structured by inches, while rulers in European countries are structured by centimeters. Moreover, other cultures may use different tools for measuring besides the ruler. Thus, visuospatial experiences are culture dependent (Pitt & Casasanto, 2020). One study illustrating the importance of culture in the development of the MNL was done in the indigenous group of Bolivia called Tsimane. This group has little formal education and modern technology, and showed no tendency to map numbers systematically to leftward or rightward space. High numbers were not related to a right space and low numbers were not related to left space. The authors hypothesize that the lack of systematic mapping may be due to the *metaphorical mental representation theory* which states that direction of mental mappings derive from observations in the natural world. For the Tsimane, such observations may not have a clear oriented direction, leading to a non-directed MNL (Pitt et al., 2021; Casasanto, 2017).

Studies have yet to establish which culturally dependent experiences are most influential for an MNL (McCrink & de Hevia, 2018). For instance, researchers disagree whether reading and writing is essential for its development. On the one hand, reading and writing is likely to impact an MNL because it involves motoric and spatial movement; consequently, strengthening the association between lineal spatial placement and shaping a mental line. Study results supported this hypothesis, with findings showing that the MNL follows the direction of reading and writing. In cultures where the reading direction is from left to right, smaller numbers are represented on the left side of an MNL, and larger on the right side. Furthermore, some studies showed a reversed pattern in cultures where the reading direction is from right to left (Shaki et al., 2012; Shaki & Fischer, 2012). On the other hand, these relationships are not found consistently (Pitt & Casasanto, 2020). For example, studies with Iranian and Israeli participants have failed to find a reversed pattern (Dehaene et al., 1993, p. 385; Shaki & Fischer, 2012).

Thus, reading and writing may not be the key impactors for the observed left to right, right to left MNL. Indeed, culture specific MNLs have been reported for children who cannot yet write or read (Shaki & Fischer, 2012) and when controlling for influences of written texts (Fischer et al., 2009). Moreover, researchers argue that both numbers and spatial factors must be present for a visuospatial association to occur. A text related to reading and writing may not include the presence of numbers. Consequently, they may not reinforce associations.

Body-based counting may have a higher potential for establishing spatial–number associations than reading and writing. It has been observed that participants who count on their fingers from left to right have strong associations. These associations were weakened when participants counted from right to left, although strengthened by training. In detail, participants who started counting on their left hand showed a smaller magnitude mapping for the left side, and a larger for the right side. And vice versa, participants who started counting from their right hand showed a smaller magnitude mapping for the right side, and larger for the left side (Pitt & Casasanto, 2020; Fabbri, 2013). Little research has been made for finger counting habits that diverge from the western left to right practice; and even less for cultures who uses whole body-based counting practices. Different counting practices could implicate the MNL in several ways. For example, it could perhaps override an otherwise innate left to right directed MNL, or it may establish and shape a non- linear MNL. If it is assumed that body–based counting may strengthen or shape spatial–number associations, then such research might reveal a key contributor in the development of the MNL.

Body–based counting is one example of embodied cognition. Embodied cognition is the notion that mental processes are greatly influenced by bodily experiences. The theory entails that all cognitive functions can be traced back to their sensorimotor activation during the related experience (Moeller et al., 2012; Werner et al., 2018). If this is true, then the MNL could be a product of prior sensorimotor experiences, such as discussed finger counting practices in which case it predicts that mental representations of numbers are directly influenced by use of fingers. Moreover, that the influence of experience stems from an association made when fingers were used to learn numbers. Once established, the associations should be bidirectional (e.g., Moeller et al., 2012). On that note, it has been observed that the positioning of arms influenced calculation preferences. When presented with multiple arithmetic tasks, participants tended to choose to conduct more tasks involving addition when following a priming of righthand movement. Moreover, when presented with lefthand movement the participants choose to conduct more tasks involving subtraction (Werner et al., 2014). Other evidence for embodied cognition is the observation that positioning of the head influences generation of numbers. In a random generating task, participants who face the left tend to generate smaller numbers than when facing the right. Moreover, the opposite pattern has been found in participants who are congenitally blind (Pasqualotto et al., 2014). These results suggest that the MNL is shaped by visual experiences. This hypothesis is strengthened by results indicating that eye movement follows the MNL. For instance, Myachykov, Ellis, Cangelosi and Fischer (2016) found that the eyes followed a left to right direction when presented auditory numerical input. Larger numbers were associated to a rightward eye drift and smaller numbers to a leftward eye drift. Similarly, one study reported that participants tend to generate smaller numbers when primed by looking left or down, and larger numbers when primed by looking right or up (Grade et al., 2013). Thus, there is evidence suggesting that visual experience, perhaps such as reading and writing, is influential in mental mapping of numerals. Furthermore, evidence suggest that sensorimotor experiences could be essential for development of the MNL, supporting the notion of a bidirectional association between sensorimotor experiences and higher cognitive functions.

In total, cultural practices related to reading/writing and body–based counting may influence the MNL. However, it is unlikely that they act exclusively. Any form of spatialized numerals should reinforce the associations between space and number. Calendars, computer keyboards, pages of magazines and other sources that involve numbers, especially across modalities, could shape the MNL (Pitt & Casasanto, 2020). Other similar and potential influencers may be the use of drawings, graphs and number lines in math classes (Göbel et al., 2011) and games where the game pieces change position and the board includes a starting and end point (Laski & Siegler, 2014). Cultural practices thus can be important for the development of an MNL, especially in facilitating sensorimotor experiences that could shape a mental line.

Effects Supporting a Mental Number Line

Several effects are assumed to indicate the existence of the MNL. Most often, the described SNARC effect is used as evidence. Further supporting arguments are based on the distance effect and the size–congruency effect. Despite the support of many studies, results opposing the notion of an MNL have been demonstrated as well. These theories argue that the observed effects supporting the MNL theory are not due to mental representations of numbers, but rather to task demands provoked by the study context. The context may have encouraged associations of familiarity, binary responses, or working memory processes. In the following paragraph, the SNARC effect, the distance effect and the size–congruency effect will be reviewed. In addition, it will be discussed whether the MNL or task demands can account for these results.

The *SNARC effect* is used as evidence for an MNL as it is believed to directly correspond to the representation of numbers. As mentioned above, smaller numbers are represented on the left side of a mental line, thus yielding shorter reaction times to smaller numbers when presented left sided. Larger numbers are represented on the right side of a mental line, thus yielding shorter reaction times to larger numbers when presented right sided (Dehaene et al., 1993). This effect has been supported by numerous studies. For instance, a recent study observed the SNARC effect for non–numerical quantifiers such as *many*, *some* and *more*. In detail, when reacting to quantifiers indicating small magnitudes, participants responded faster when using the left hand. When reacting to larger magnitudes, participants responded faster when using the right hand (Abbondanza et al., 2021).

A second effect which is used as evidence for the existence of the MNL is the *distance effect*. This effect describes the tendency to faster discriminate between numbers that are far apart in magnitude (e.g., 1 and 9) compared to those which are closer in magnitude (e.g., 1 and 2). A typical task used to investigate the effect is magnitude comparison. Participants are asked which of two numbers is the greater or lesser one. When the reaction time between a set of numbers closer in magnitude is longer than the reaction time between a set of numbers with larger magnitude, then the distance effect is observed. The distance effect has been shown in several experimental settings (e.g., fractions; DeWolf et al., 2014) and across different age groups (e.g., Gibson & Maurer, 2016). In relation to the MNL, it has been argued that larger and smaller numbers are represented with distance to each other on the mental line. Additionally, it has been suggested that numbers of similar magnitude are represented in proximity. If this is the casr, then it should be more difficult to discriminate magnitudes with smaller distances between them and easier to discriminate between magnitudes which have greater distances between them (Dehaene & Changeux, 1993).

Lastly, the *size–congruency effect* refers to the tendency to more quickly judge a small number as small, when it physically appears small (e.g., 2) and to more quickly judge larger numbers as large when they physically appear larger (e.g., 9). When in incongruency, say, a large number appearing smaller than a small number (e.g., 5 and 3), the reaction time is higher than for congruent trials (Besner & Coltheart, 1979). Some authors hypothesize that the effect reflects a learned MNL, due to the fact that the value of a symbolic number would have to be comprehended in order to compare it to its physical size. When both its value and its physical size would match (e.g., both match "large") then activation of both could take place by the same attribute (Sobel et al., 2016; Weis et al., 2018).

Alternative Accounts

The MNL has been argued to cause the SNARC effect, the size–congruency effect and the distance effect. However, another possibility for the observed effects is that they are grounded in task demands. According to this theory, the observed effects are limited in time because they are manipulated in the experiments. Therefore, they do not reflect long-term associations as claimed by the MNL theory. For instance, the task can be of binary nature, requiring the participant to respond in two categories. Indicating which number is smaller vs. larger, upper vs. lower, nearer vs. further are all examples of such. To illustrate, when participants are asked to use their right hand or left hand to indicate which number is smaller or larger, it may seem like a SNARC effect occurs, although it is rather a *polarity effect* where each hand is assigned to categories *small* or *large*. This theory stresses that when the polarity dimension and the response dimension are the same, then the processing is quick. If the response dimension and the polarity dimension are incongruent, then the processing is slower (Winter et al., 2015).

Despite the growing interest in the polarity account, the explanation cannot justify for results indicating a SNARC effect when no poles were given, for instance why smaller numbers are generated after being primed with left–handed stimuli, and why larger numbers are generated after being primed with right–handed stimuli (Pasqualotto et al., 2014). On that matter, a *constructive working memory* explanation might be more plausible. This explanation argues that mental positions of numbers are not fixed but rather constructed and processed as the task is being executed (Aulet et al., 2021). When a constructive working memory explanation is assumed, then other ordinal sequences besides numerals should demonstrate similar results. However, research is not consistent regarding other ordinal sequences. While some studies found a SNARC effect for letters and months (e.g., Gevers et al., 2004; 2003), others have not (e.g., Aulet et al., 2021).

Lastly, the observed effects could be explained by *familiarity* of numbers. One study manipulating number sequences found that the sequence 1–2-3 was processed faster than any other presented sequence, including descending sequences and higher number sequences. The results thus had an absence of a distance effect. Recognition of the 1–2–3 sequence might be why participants had a quick reaction to it, as this particular sequence is present in everyday life (Sella et al., 2020). The familiarity account seems to have produced strong arguments, and thus its claims cannot go unnoticed.

In sum, whilst the SNARC-effect, the distance effect and the size-congruency effect has been used as evidence for the existence of an MNL, alternative explanations for the observed effects cannot be ruled out. Binary category response, familiarity and constructive working memory influences are plausible and should be further investigated. However, a majority of studies support the MNL as the main contributing factor of the effects.

Cognitive Implications of the Mental Number Line

Research shows that the MNL may pose several cognitive benefits, many of which promote mathematical abilities. For instance, training of the MNL is shown to increase symbolic math abilities (Park & Brannon, 2013). Symbolic math representations are precise knowledge of number magnitude. One example is the knowledge that "three of something" can be represented by the symbol "3". Some researchers argue that such abilities develop in parallel to the MNL. Specifically, children gain numerical knowledge in several informal activities such as games, which are then mentally mapped and attached to a specific symbol, increasing symbolic math abilities (Li et al., 2018). Another evident cognitive benefit from a strong MNL is mental rotation. Mental rotation is a visual–spatial ability to mentally rotate one object to see if it matches another. A typical task to assess mental rotation ability is to present the participant with different items of which one matches the original. The participant must mentally rotate the items and determine which one is identical to the original. In order to do so, both mental image processes and working memory processes are required (Shepard & Metzler, 1971).

Recent studies have also found support for number line estimation mediating the relationship between mental rotation and arithmetic abilities (e.g., Yang & Yu, 2020; Thompson et al., 2013). It indicates that a comprehensive mental representation of magnitudes correlates to mental rotation skills, which in turn could affect mathematical performance. As mental rotation is a spatial ability, the basis for this mediation relationship could be spatial involvement in the MNL. Other studies further strengthen the notion of spatial involvement in mediating relationships between the MNL and arithmetical skills. For instance, the MNL has been shown to mediate the relationship between spatial skills and calculation, as well as between spatial skills and word-problem solving. Word–problem solving is the competence of transforming word problems into understandable and realistic visual or mental models, which involves processes related to language, presentation and calculation (Mayer, 1985). To exemplify, “you want to buy a pair of pants that are on sale for 20%. Their original price is 100 euros” is a word problem that can be translated into mathematical calculations and be solved using the MNL. It is feasible that spatial factors evolve into an MNL when taking into consideration the previously discussed potential of spatial involvement in the development of the MNL. The MNL is then used as a mathematical tool, consequently mediating arithmetic relationships (Pui Tam et al., 2018). In total, there is evidence that claims the MNL could be a substantial tool for other abilities apart from number representation.

The Admiralty Islands

Most of the reviewed studies use western participants. It is necessary to investigate the MNL in other non-western cultures, as the Admiralty Islands, to ensure generalization of results. On that note, Melanesia is one of three island areas in the Pacific that make up Oceania, along with Polynesia and Micronesia. It is an area with “fuzzy edges” (Keesing, 1982, p. 5), which has led to some confusion about the borders of the regions. Hence, it is not unusual to find that some authors report some islands as belonging to Melanesia, whilst others report that the same islands belong to Micronesia or Polynesia. Despite the disagreement, the majority states that Melanesia consist of New Calcedonia, Solomon Islands, Vanuatu and Papua New Guinea (e.g., Kessing, 1982; Schokkin, 2014). The Admiralty Islands is an island group belonging to Papua New Guinea (Goetzfridt, 2008). Manus and Los Negros are the two largest islands of the area, the rest consisting of smaller islands and villages (Healey, 1976, pp. 356–357). A map over these geographical areas is depicted in Figure 1. Not depicted on this map are the smaller islands around Manus as well as the villages on Manus. These can be found in Appendix B, and if wished their geographical location on a map can be found on the Glottolog webpage by using the code “admi1239” (Hammarström et al., 2021).

Culture and Language

Manus is the home for 60 485 people (Citypopulation, 2019) The people of Manus were traditional fishers who traded their fish for food and building supplies to sustain their groups. For men it was not uncommon to voyage for longer periods of time, in the hopes of good catch and reward (Mead, 2017, p. 1). Some people living on smaller islands surrounding Manus, such as Buluan, were mainly agriculturists who grew vegetables and fruits such as taro, yams, bananas and sugarcane. The people of Manus and of the surrounding islands met frequently at trade markets to exchange goods between the villages (Schokkin, 2014).

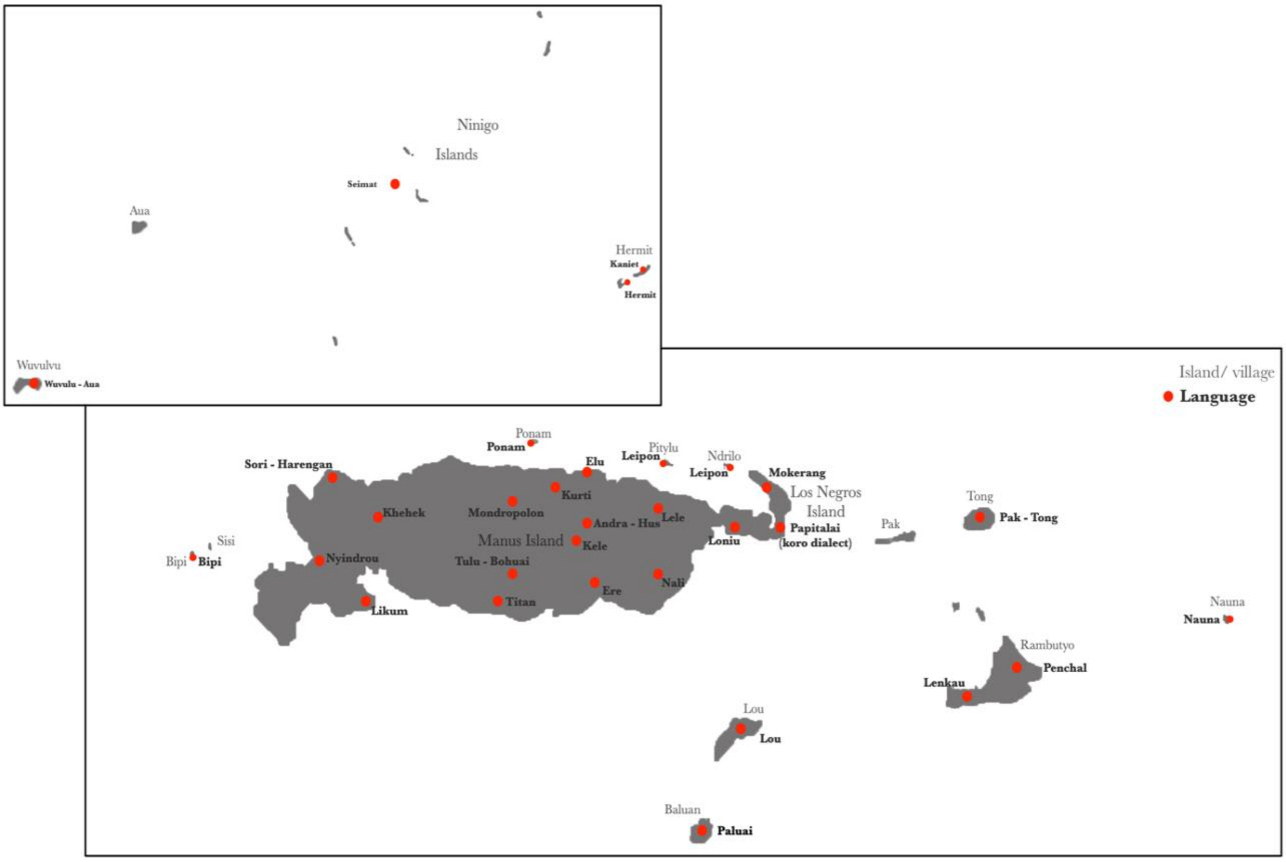

Figure 1. Areas of the Admiralty Islands and its languages.

The Admiralty Islands have a long history as being colonized. The first Europeans to visit were Spanish, however they never settled permanently on the Admiralty Islands. Between 1884 and 1914 the Admiralty Islands were a German colony, and from 1914 to it was under Australian rule. Between 1942 and 1944 Japan occupied the islands (Brookfield, 1972, p. 59). The influence of colonialization is still present in the modern Manus, which is influenced by labor in Australia and trades with Japan (Guillemin, 2017, pp. xxi-xxii). Other traits of modern Manus include that foods that are not grown on the island such as rice and coffee are imported and sold in stores (Schokkin, 2014). Furthermore, it is now common for people move away from the islands after getting an education, and therefore many of the islands and villages are abandoned (Guillemin, 2017, pp. xxi-xxii). The geography is mountainous, covered with large areas of rainforests and rivers (Boettger, 2016).

The languages of the Admiralty Islands are part of the Austronesian language family. Austronesianists (e.g., Tryon, 1982) argue that there was once one language in the Pacific. The language, called Proto–Oceanic, is the ancestor of all Oceanic languages including those spoken on the Admiralty Islands (Owens, 2018, p. 12). Glottolog (Hammarström et al., 2021) reports 31 languages on these Islands, an extraordinary high number according to the land area. Indeed, Melanesia is home to about 1300 of the approximately 6900 languages in the world, making it the highest concentration of languages per area. The numerous amount of languages could partly be due to its mountainous landscape which separates the villages from each other (Landweer & Unseth, 2012). However, while the language count is high, the differences between the languages are small. One field worker at Manus reported, although somewhat long ago, that all the people seemed to speak one language with slight variation. Moreover, the people of Manus consider themselves as one group (Mead, 2017, p. 4).

It should also be noted that there are many inconsistencies between the names of the villages and their languages, possibly due to migration in the area. Over the last century, inhabitants of the islands have been moving around the area, often changing the names of the villages they settled in. Consequently, many of the languages have been mixed up, and the villagers have become multilingual (Healey, 1976, p. 358). Immigration from other villages was in certain cases due to religious reasons. The traditional Manus people were deeply religious, and when something bad happened (e.g., adultery or death) some people moved to create distance between themselves and "the bad spirits" (Mead, 2017, p. 9-10).

The Eastern Admiralty Islands include the languages depicted in Figure 2 (Hammarström et al., 2021). A map over the languages of the Admiralty Islands according to geographical area is depicted in Figure 1, and an overview of linguistic grouping is depicted in Figure 2. In the following parts of this thesis, data on number systems on the Admiralty Islands will be summarized and later discussed in light of mental number representation.

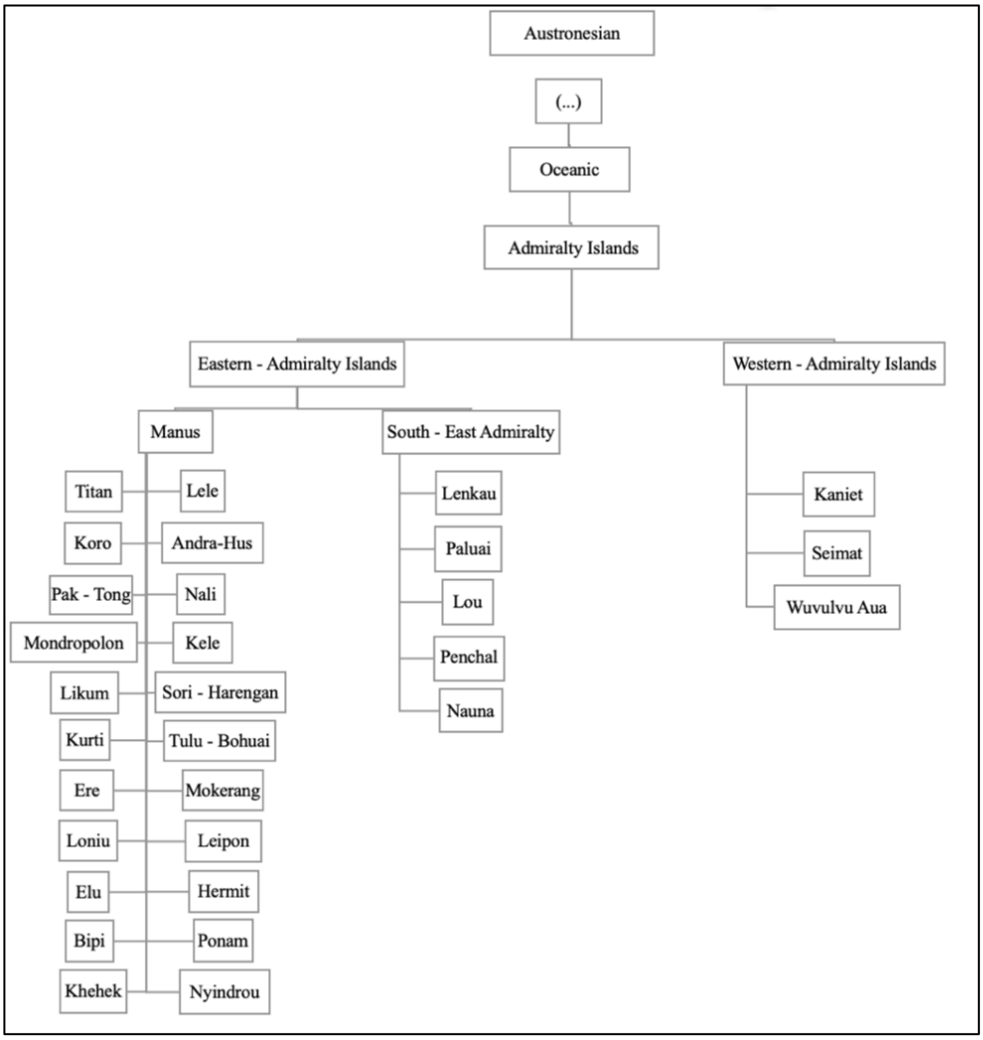

Figure 2. Linguistic grouping of the Admiralty Island languages.

Status of Research

Owens, Paraide and Muke provides discussions and overview of several of the counting systems of the Admiralty Islands languages based on fieldwork from Lean in *History of Numbers* (2018). Descriptions of number words for some languages are also included in doctorial theses based on fieldwork (Boettger, 2015; Cleary-Kemp, 2015; Schookin, 2014; Hafford, 2015). Other authors have similarly reported number systems for Admiralty Island languages when doing linguistic work in specific villages (e.g., Carrier, 1981; Hamel, 1994; Fischer, 2010). Furthermore, Smythe and Z´graggen (1975) and provides number words 1 to

10, 100 and 1000 for many of the Admiralty Languages. Blust (2021a) has given descriptive information about linguistics and number systems for eight of the languages in a special issue of *Language and Linguistics in Melanesia.* Apart from these sources, little documentation on the languages of the rapidly disappearing languages of the Admiralty Islands is available (Blust, 2021b).

Number Systems in the Admiralty Island Languages

The aim of the present study was to document data on the number systems on the Admiralty Islands and to work out their characteristics in order to answer the question *how these number systems may affect the mental number line.* Glottolog was used to list the number of languages on the Admiralty Islands, after which, numerical data on these languages was gathered from literature. The following databases were searched for relevant literature: Google Scholar, ScienceDirect, PubMed, APA Psychinfo, PubPsych, as well as the library webpage of the University of Bergen. An overview of the collected number systems can be seen in Table 1. For most languages numerals of 1 to 10 were obtained, except for five: Nali, Elu, Mondropolon, Lenkau and Lou. These could not be found and are thus not in Table 1. Neither the language Khehek was attained, and for that reason, Levei, a dialect of Khehek, was added as an indicator of what this language may be like. In total 25 languages (including Proto–Oceanic) and 1 dialect were added to Table 1. An overview of the sources for the collected numerals can be found in Appendix B. The next paragraphs will be used to map out common characteristics observed in the counting systems and discuss how they may influence the development of the MNL. Specifically, the characteristics are related to range, dimensions and scale.

Table 1

Serial numbers (n) and basic numbers for powers of the base (P) in Proto - Oceanic and in some Admiralty Languages

			Admiralty languages and dialects				
	Number	Proto-Oceanic	Andra	Hus	Lele	Koro	Titan
	1	ta-sa, sa-kai, tai, kai	si	si	sa	ti-h	esi
	2	rua	luoh	luoh	ru	mo-ru-wah	eluo
	3	tolu	taloh	daloh	dul	ma-tala-h	etalo
	4	pat(i)	hah	hahuh	ha	ma-ha-hu	ea(h)
n	5	lima	limeh	limeh	lim	ma-lima-h	elima
	6	onom	wonoh	onoh	en	ma-wono-h	ewono
	7	pitu	andrataloh	haraloh	enrdul	ma-ndo-tala-h	andratolo
	8	walu	andraloh	holuoh	ndroru	ma-ndo-ru-wah-ma-ndo-ru-mou	andraluo
	9	siwa	andrase	hosi	ndrosa	ma-ndo-ti-h	andrasi
	10^1	sa[-nga]-puluq	sanguh	senuh	ma-sungul	ma-son-ngul	eakou
P	10^2		sangat	sanat	ma-sou-pou		sanat
	10^3		sapau	sa-bo	ma-po-sih		pue-si

Note. n = number and P = power base (i.e., exponent), references can be found in Appendix B.

		Admiralty languages or dialects						
	Number	Kurti	Ere	Kele	Leipon	Ponam	Loniu	Mokerang
n	1	sih	sa	si	dijx	si	sih	si
	2	ruweh	ru	ruwe	marui	luof	ma uoh	ma wo
	3	toloh	dul	telo	madjalo	talof	macoloh	madjalo
	4	hahu-u	ha	hahu	mahah	faf	mahah	maha
	5	limueh	lim	limue	malime	limef	malimeh	majime
	6	onoh	en	enih	mawono	wonof	mawonoh	mawono
	7	ondro-taloh	enrdul	n´dretelo	madadjolo	ahatalof	ma arucoloh	maridjalo
	8	ndro-ruweh	ndroru	d´droruwe	madurui	ahaluof	ma aru ouh	maru wo
	9	ndro-sih	ndrosa	n´drusei	madudix	ahase	ma arusih	marusi
P	10^1	sungoh		sugah	masunol	sanguf	masonon	masonol
	10^2	sede/sangat		sangat	masinet	sangat	masanat	masanat
	10^3	po-sungoh		e-pou	mandubou	sapau	mapun sih	masubo
	10^4	po-sangat					mapunsonon	
	10^5	po-hopou						

		Admiralty languages or dialects						
	Number	Pak	Bipi	Hermit	Nyindrou	Sori	Levei	Likum
	1	dih	sih	hip	ari	sip	eri	esi
	2	huoh	xuoh	xuop	la uh	huop	lueh	rueh
	3	duluh	taloh	tarop	taloh	tarop	toloh	taloh
	4	dalor	hah	babu	hahuw	papuw	hahup	hahu
n	5	nuron	limeh	limep	limeh	limep	limeh	limeh
	6	wonoh	wonoh	wonop	onoh	gonop	cohahup	chohahu
	7	darluh	adritaloh	axitarop	dro-taloh	ehe-tarop	cotuloh	chotaloh
	8	darhuoh	adroxuoh	adaxuop	dro-lauh	anu-huop	colueh	chorueh
	9	dardih	adroshi	adehip	dro-ari	anu-sip	coeri	choesi
	10^1	sonoh	sanon	hanop	ronoh	sonop	ronoh	senoh
P	10^2	sanar	sanak	hanat	rinek	sana	ranat	sinak
	10^3	lasan dih	sapwaw		rawa	sabw	rohop	rawa

		Admiralty languages or dialects						
	Number	Tulu	Paluai	Nauna	Penchal	Kaniet	Seimat	Wuvulu-Aua
n	1	eri	som	sew	siw	tef	tehu	ai(ai)
	2	luweh	yumou	ruh	lup	wa	huohu	guai
	3	toloh	tulumou	tuluh	tulup	tohu	toluhu	oduai
	4	ha-hup	pamou	talet	talit	faf	hinalo	guineroa
	5	limeh	ngunan	tuten	rurin	mia	tepanim	aipan
	6	choha-hup	ngonomou	tuten a sew	unup	tohinjet	tepanim tehu	oderoa
	7	chotoloh	nganorulumou	tuten a ruh	karutulup	kodohu	tepanim huohu	oderomiai
	8	choluweh	nganoyumou	tuten a tuluh	karulup	kouehu	tepanim toluho	vaineroa
	9	cho-eri	nganosom	tuten a talet	karusiw	kodef	tepanim hinalo	fvaineromiai
P	10^1	ronoh	sangal	sanahul	sanahul	hemidin	huo-panim	vapa ani
	10^2	ranak	songot	sanet			patei-tel	
	10^3	ropop	mwason	mocon sanahul				

Homogeneity

The results show interesting traits about numerical systems on the Admiralty Islands. First, it is noticeable that numeral words across the languages are highly similar (i.e., homogeneous). Although the number of languages is vast, many of them either directly share or contain similar numerals. This is because the numbers are cognates, meaning that they are descendants from the same language (Tryson, 1982). To illustrate, the numerals 1, 2, 3, 4 and 5 in Nauna and Penchal are almost identical to each other (Blust, 2021d, Blust, 2013, p. 280). Both languages are displayed in Table 2, bolded. It should be noted that as they are geographically close to each other the chance of these languages intertwining and trading words are higher than for languages with larger geographical distance. Such being the case, the languages of the Admiralty Islands may be considered as separate following political and cultural factors above the linguistics (Schokkin, 2014).

Also the numeral words for 1, 2, 5, 10 and 100 are similar between languages. For example, the word for 1 is *si* in Andra, *sa* in Lele and *sih* in Loniu (Smythe & Z´graggen, 1975; Boettger, 2015; Hamel, 1994). The word for 2 is *luoh* in Andra, *luof* in Ponam and *huoh* in Pak (Smythe & Z´graggen, 1975; Carrier, 1981, p. 475; Blust, 2021f). The word for 5 in most of the languages is a variant of *lima*, referring to "hand" (Owens et al., p. 84). In Andra the word for 5 is *limeh*, *majlime* in Mokerang and *limueh* in Kurti (Smythe & Z´graggen, 1975; Fischer, 2010). The word for 10 is *sanon* in Bipi, *sonop* in Sori and *senoh* in Likum (Blust, 2021g; Blust, 2021h; Blust, 2021e) Lastly, the word for 100 is *sanat* Titan, *sangat* in Ponam, and *sana* in Sori (Smithe & Z´graggen, 1975; Carrier, 1981, p. 475; Blust, 2021h). The similarity in languages may support the hypothesis that all Oceanic languages stem from one Proto–Oceanic original language, that has then been modified and shaped by the culture.

Table 2
Serial numbers in Nauna, Penchal and Likum with direct translation

Number	Nauna	Literal translation	Penchal	Literal translation	Likum	Literal translation
1	**sew**	one	**siw**	one	esi	one
2	**ruh**	two	**lup**	two	rueh	two
3	**tuluh**	three	**tulup**	three	taloh	three
4	**talet**	four	**talit**	four	hahu	four
5	**tuten**	five	**rurin**	five	limeh	five
6	tuten a sew	five and one	unup	six	chohahu	ten minus four
7	tuten a ruh	five and two	karutulup	seven	chotaloh	ten minus three
8	tuten a tuluh	five and three	karulup	eight	chorueh	ten minus two
9	tuten a talet	five and four	karusiw	nine	choesi	ten minus one
10	sanahul	ten	sanahul	ten	senoh	ten

Note. References can be found in Appendix B.

Regularity

A second noticeable characteristic is that are many of the counting systems are regular in the sense that counting numerals seem to follow predictive patterns. Most of the languages are base-10 systems, meaning that numbers are constructed from ten base numerals. A minority portion of the numerical systems are base-5 systems (Owens et al., 2018, p. 76). These systems contain numerals contracted of five base numerals. Numbers can be constructed by means of multiplication, addition or subtraction of numbers (Wolfers, 1972, p. 218). Nauna is an example of a regular number system where addition is used (see Table 2). In Nauna, the numerals 6 to 9 consist of base 5 and one number from 1 to 4. To exemplify, the word for 6 is *tuten a sew*, with *sew* = 1 and 5 = *tuten.* Number eleven is composed of 10 and 1, *sanahul a sew* (Blust, 2021d). To compare, English is a partly irregular number system where for example 11 is not “10 and 1”, but rather *eleven* (Overmann, 2018). Other number systems that are either partly or fully regular are Ponam, Nyindrou, Likum, Tulu, Seimat, and Kurti (Blust, 2021e). Likum compose the numbers 6 to 9 based on subtraction rather than addition (see Table 2). The number 1 is *esi* and the number 9 is *choesi* meaning “10 minus 1”. Note that the direct number word for 10 is *senoh*, suggesting that *cho* is a prefix used to indicate “ten” for numbers below ten (Blust, 2021e). Other common number prefixed include *ma* and *pu* for smaller numbers (Blust, 2021d). Wuvulu-Aua numerals 6 to 9 are based on a combination of addition and multiplication of other smaller numbers. For example, the number for 3 is *oduai* and the number 6 is *oderoa* meaning 3 x 2. The number 7 is *oderomiai* meaning (3 x 2) + 1 (Owens et al., 2018, p. 101).

Small Numbers

A third observed characteristic of the number systems is that a minority of the languages contain large numbers. For instance, many of them contain numbers for the powers of the base up to 1000 (see Table 1). Some, such as Loniu, have numbers up to 10 000 (Hamel, 1994). And Kurti report numbers up to 100 000 (Fischer, 2010). However, really large numbers (i.e., above 100) are not reported to the extent they are in neighboring Polynesia and Micronesia (Owens et al., 2018, p. 160). For Polynesia, some authors hypothesize that large numbers could be motivated by socioeconomic reasons. They observed that the extent of numbers correlated with population size. On these islands, exporting and importing goods may have been essential for economy, hence creating a need for high numbers for the purpose of counting (Bender & Beller, 2011). As the Admiralty Islands likewise were engaging in trading, they might similarly have had a need for high numerals for counting. However, the lack of consistent reports of really large numbers in Melanesia suggest that socioeconomic reasons perhaps did not facilitate a need for large numbers to the same extent as in Polynesia. Accordingly, the reported large numbers may have been used to describe any quantity too large to count, instead of specific values (Owens et al., 2018, p. 162). This claim is supported by the collection of seemingly spontaneous large numbers of Admiralty Island languages. For instance, Titan numerals 1 to 10, 100 and 1000 were retrieved in data collection (Owens et al., 2018, p. 99, 156; Smythe &

Z´graggen, 1975). The absence of numerals between 10 and 100, as well as between 100 and 1000, suggest that large numbers may have been used as a metaphor for theoretical limitless numbers.

On a related note, some authors have observed that some large numbers on the Admiralty Islands change in their regular construction. Andra-Hus, for instance, use *sa-po* for 1000, *lu-po* for 2000 and *tulu-po* for 3000. Following this pattern, it is reasonable to assume that the term for 10 000 would consist of the number word for 10 plus *po.* However, this is not the case as the number for 10 000 is *pue-sih.* Authors note that the change in regularity demonstrate cases of where a counting system previously ended. When there was a need for more numbers in the counting systems they were added but not necessarily following the same construction as prior numerals (Owens et al., 2018, p. 156). If large numbers indeed have been added to the counting systems because there was a need for higher counting units, then there should be reports of large numbers in the counting systems of the Admiralty Islands languages. Some reports of large numbers do exist. For instance, authors report am extensive amount of numerals for Ponam (Carrier et al., 1981) and for Wuvulu (Hafford, 2015). However, the collection of counting systems on the Admiralty Islands showed a lack of really large numerals for most languages, and for that reason predictions are made on the basis of smaller numbers. Nonetheless, it is worth mentioning that really large numbers may exist in the counting systems but that they are not well documented.

Numerical Classifiers

Another mentionable trait is the use of classifiers on the Admiralty Islands. General numerals in classifier languages, such as those presented, are used mainly for enumeration (Bender & Beller, 2011). When referring to quantities, the use of numerical classifiers is perhaps preferred. Numerical classifiers were found reported only within some of the numerical sources (examples can be found in Appendix B), although authors state that numerical classifiers are used in every Manus language (Owens et al., 2018, p. 99).

Classifiers are group of morphemes that are used to categorize nouns, where the categorization is mostly dependent on a shared characteristic. Many languages have numerical classifiers that are associated to certain objects (Bender & Beller, 2011). To compare, the English language is limited in the use of classifiers and only make use of them under certain conditions. One comparable example of an English classifier is “a handful of sand” (Blust, 2013, p. 291). Here, the noun “handful” is accompanying and classifying the object “sand”. Besides their classifying function, classifiers are used to quantify masses. In which case, the classifier directly function as a unit (Bender & Beller, 2011; Owens et al., 2018, pp. 99-100). For example, *a dozen*, referring to *twelve of something*. In so, classifiers can be a numerical tool. Such cases are interesting because they may indicate what is important to a culture, or what is of practicality.

Some branches of the Austronesian languages contain a large amount of numerical classifiers (Bender & Beller, 2011). Some of the ones found in the Admiralty Islands are listed in Table 3 as examples, and a brief overview can be found in Appendix B. To illustrate, Kurti and Koro languages include classifiers for counting materials, such as logs and sticks, baskets and cups (Cleary-Kemp, 2015; Fischer, 2010). Logs, sticks and cups are all supplies that were essential for building huts and canoes. Moreover, baskets were used by women around their hips to transport items to trade markets (Boettger, 2015). Additionally, they all are comparatively small objects that would benefit from being counted in groups such as by tens. Taken together, the need for such supplies and the benefit of grouping may have evolved into specific classifiers (Deahene, 1992: Bender & Beller, 2011

Although the Oceanic languages have an extensive number of classifiers it should be noted that the use of numerical classifiers is decreasing (Boettger, 2015). The decline may be due to modern advances changing the culture and its need for specific classifiers (Blust, 2021i). Counting spears, for instance, may not be of importance anymore and thus the new generation may not be taught its related classifying words.

Table 3
Numerical classifier examples for Kurti and Koro

Language	Number	Numerical classifier and associated number		
Kurti		*Pools of water*	*Houses and huts*	*Trees, logs and sticks*
	1	hopuil	sim/hopuing	he-ei
	2	rupuil	rupuing	rui-i
	3	tulupuil	tulpuing	tuli-i
	4	hapuil	hapuing	hae-i
	5	lipuil	lipuing	limi-i
Koro		*Houses*	*Baskets*	*Cups*
	1	t-em	ta-hat	ta-kah
	2	mo-ru-wem	mo-ru-hat	mo-ru-kah
	3	ma-tilu-wem	ma-tulu-hat	ma-tulu-kah
	4	ma-ha-yem	ma-ha-hat	ma-ha-kah
	5	ma-limi yem	ma-limi-hat	ma-limi-kah

Note. References can be found in Appendix B.

Mental Number Line Characteristics for Admiralty Islands Counting Systems

Having assessed several distinctive characteristics of the counting systems of the Admiralty Islands, it is useful to consider how they relate to the common characteristics of the MNL. The regularity and organization of the counting systems on the Admiralty Islands could have implications for possible dimensions of number representations. The observed regularity in the counting systems and the lack of high numerals could influence the range of the MNL. Lastly, cultural influences such as formal education may affect its scale. In the following paragraph these points will be highlighted. The predictions made are expected for most of the languages given the similarity of the counting systems. Variations nevertheless may occur.

Dimensions

Authors distinguish between one-dimensional (1D) and two-dimensional (1 x 1D) number systems. One- dimensional systems are those where each number word is associated to a lexeme such as body parts. An MNL shaped from body-counting practices may be curved following the shape of the body and have numbers mapped onto specific body parts. For instance, 1 may be mapped on a part of the line which corresponds to the thumb of the left hand and 10 perhaps on the pinky finger of the right hand (Bender & Beller, 2011). The importance of the body for counting systems is reflected in the observation that various number words resemble words for body parts. As mentioned, the word for 5 is in many of the languages is a variation of *lima* meaning hand (Owens et al., p. 84). In Seimat the word for 20 means “person” or “human being” which is refering to the total amount of toes and fingers, and the word for 100 means “five people” (Blust, 2021c). However, some authors note that the Admiralty Islands do not seem to have many body-based counting systems despite the commonalities between number word and body parts (Owens et al., 2018, p. 65). To illustrate, the citizens of Ponam do not learn numbers by counting on their fingers but rather by counting objects (Carrier, 1981, p. 468). On that note, body-based counting may have been the prevalent method of counting when numbers were primarily spoken. In modern times numbers are primarily written, and thus the need for a full body-based could perhaps not be as necessary anymore. Consequently, the perceived association between body part and number word may have disappeared, leaving number systems seemingly independent from connotations of the body (Owens et al., 2018, p. 128).

A two-dimensional system is one with a finite set of numerals which are combined to create larger numbers (Bender & Beller, 2011). Most of the Admiralty Islands counting are base-10 systems with a finite set of numerals are 1 to 9 (Owens et al., 2018, p. 76). Moreover, they can be called two-dimensional because the finite set of numerals can be used in combinations to produce larger numerals. To exemplify, the Kele word for 3 is *telo* and the word for 10 is *sugah.* When combined with a prefix they created the number 13 *sungah pe telo* (Owens et al., 2018, pp. 322-324). Some authors hypothesize that the MNL of two-dimensional number systems could have the format of a table with rows and columns where the finite set of numerals represented horizontally and the powers of the base are represented vertically (Bender & Beller, 2011). Perhaps, such a representation is possible for the counting systems of the Admiralty Islands. A model following this thought is illustrated in the last parts of the thesis.

Range

When it is assumed that number systems influence mental number representations, then the range of the MNL should follow that of the counting systems (Bender & Beller., 2011). As mentioned, most counting systems on the Admiralty Islands are base-10 number systems which suggests a mental mapping for numerals 1 to 9 (Owens et al., 2018, p. 76). Furthermore, most contain numerals up to 100 (see Table 1). Mapping of numerals above 100 could also be predicted in individuals who use number systems containing larger numbers. This claim, however, is a subject of debate. On the one side, researchers argue that high numbers in Polynesia are used solely metaphorically, and that they have no counting purpose (Clark, 1999). This argument is in line with the claim that general numerals in classifier languages are used mainly for enumeration (Bender & Beller, 2011). On the other side, researchers argue that high numbers on Manus are indeed used for counting. For instance, counting may be used in ceremonies; in gift giving between group members; as well as for “bride-prize” which symbolizes the money paid to a bride´s family when a couple is getting married (Schokkin, 2014, Fischer, 2010). It should be noted that these traditions may be of the past and not exercised anymore.

Regardless of the validity of both sides of the discussion, it is likely that really large numbers are not represented on the MNL for most Admiralty Islands speakers. This prediction is based first and foremost on the observation that really large numbers were not found for most number systems (see Table 1) and because authors claim that numbers which are smaller in magnitude are more likely to be represented on an MNL as opposed to numbers larger in magnitude (Brysbaert, 1995). Nevertheless, large numbers could easily be constructed due to the regularity observed in the number systems. Generating the number 250, for instance, could for some of the languages be done by (5 x 10) + 200. Taken together, an MNL range between 1 to 100 can be predicted for users of the Admiralty Islands counting systems.

Scale

Observations from western studies support the statement that representation of numbers initially follows a logarithmic scale that gradually becomes more linear after exposure to formal schooling (e.g., Berteletti et al., 2010). Some non-western studies have made similar conclusions. To exemplify, the Yupno is a community in Papua New Guinea with little formal schooling that applies a non-linear scale. Such results indicate a universal tendency to use a logarithmic scale and that the use of a linear scale can be further developed if taught (Núñez et al., 2012). Formal schooling may be especially influential for the development from a logarithmic to a linear scale as it introduces individuals to numerical knowledge. The knowledge that all immediate numbers have the same distance to each other regardless of magnitude is perhaps of particular value. This is because a linear line has equal number intervals while the intervals in a logarithmic line differ (Dehaene, 2007, pp. 527-574; Gallistel & Gelman, 2000).

Many of the Admiralty Islands have formal schooling which would suggests an MNL of linear scale. For instance, Ponams have attended Pidgin language mission schools since 1920

(Carrier, 1981, p. 468). It is however observed that the scale for really large numbers remain logarithmic despite formal education (Dehaene & Marques, 2002). Although this could possibly impact the MNL amongst Admiralty Island inhabitants, it is not expected to due to their lack of really large numbers and due to the notion that large numbers are less likely than small numbers to be represented on the MNL (Brysbaert, 1995).

Influences of Culture and Embodied Experiences

The modern Admiralty Islands have adopted various western counting measures. For instance, Ponams speak of time in hours and minutes, they use kilogram and pounds as units of measure for weight, and feet and meters as units of measure for length (Carrier, 1981, p. 469). These are all possible reinforcers of a left to right MNL. To illustrate, hours range from 00 to 24 and can be imagined as a timeline where the earlier hours are represented at the beginning and the later hours at the end. Following that example, small numbers may be associated to the left side of the timeline associated to morning or day and the larger numbers to the right side of the timeline associated to evening or night.

Other potential influencers of an MNL are number games and weaving. Engaging in number games enables individuals to practice number skills such as multiplication, addition and subtraction. "Lucky" was once a common gambling game played at the island of Ponam. In this game all players are dealt three cards of which their numerical value is added together. Next, the first digits of the total value of the three cards are disregarded leaving the players with one number of which the highest value wins (Carrier, 1981, p. 169). "Lucky" may still be played at the island, or it could have been exchanged for other more modern games. Nevertheless, the existence of "Lucky" shows that number games were once a part of the culture. And even if the game is discontinued, the tradition of playing games involving numbers may have been carried on. Another diminishing tradition is that of weaving. Weaving is a traditional activity amongst

Kurti women. The woven patterns are passed down through generations and usually unique to one group or family. Moreover, many of the patterns are symmetrical and require calculation to enable exact replication. Researchers have argued that the women perhaps take use of a coordinate system with a horizontal and vertical axis to ensure symmetry. Such a system could reinforce associations of a two-dimensional MNL and thus be influential for number representations if still practiced (Fischer et al., 2010).

Mental Number Line Models for the Admiralty Islands

At this point some predictions for an MNL amongst individuals using the counting systems of the Admiralty Island can be made. First, as has been argued that representations are two-dimensional. Secondly, the MNL is expected to contain representations for numbers ranging from 1 to 100. And lastly, the MNL can be assumed to follow a linear scale due to factors such as formal schooling. With these three predictions in mind, it is possible to argue for at least two approximate models for mental representation of numbers. The final parts of this thesis will be used to argue for and sketch out possible MNLs for counting systems on the Admiralty Islands.

Two possible models for the MNL amongst individuals using the counting systems of the Admiralty Islands are depicted in Figure 3. While they vary, they are based on the predictions made for dimensions, range and scale. It is important to emphasize that although their characteristics are based on predictions made from prior study results, the models themselves are based on speculation.

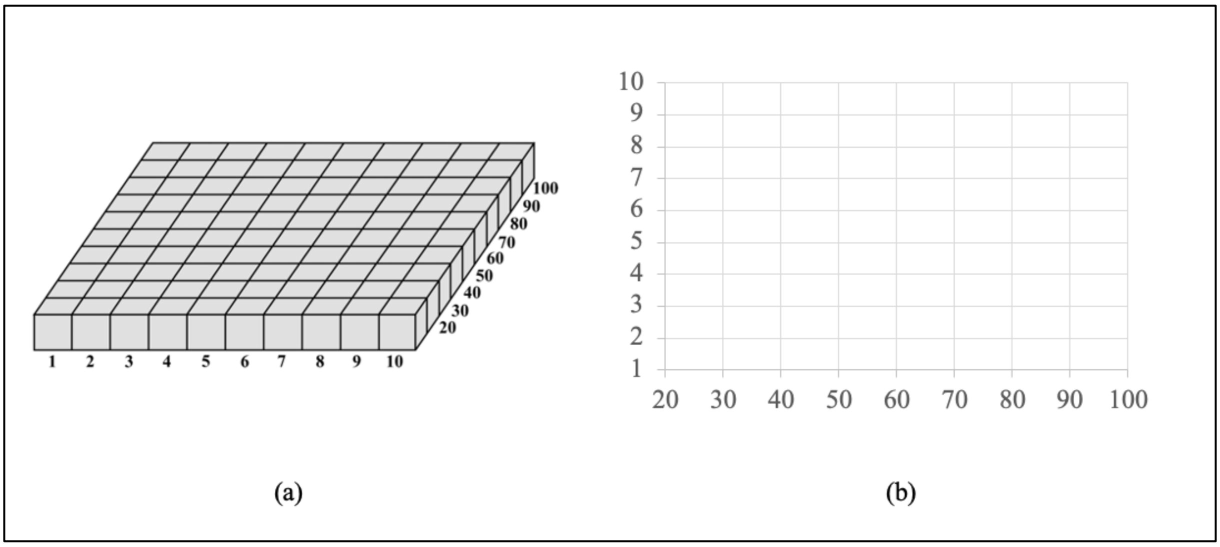

Figure 3. Possible mental number representations: (a) multi-dimensional representation inspired by of Bender & Beller (2011), (b) a number line motivated by cultural influencers such as weaving inspired by Fischer (2010).

Model (a) depicts a possible MNL for serial counting numerals (i.e., numerals used for enumeration purposes) based on two-dimensions and a linear scale. This MNL model is proposed as developed from a counting systems that have a finite set of numerals which combined creates larger numerals (Bender & Beller, 2011). This is the case for most of the counting systems of the Admiralty Islands (Owens et al., 2018, p. 76). The “boxes” depicted in the model may function as building blocks, so that by combining several boxes a larger number is “built”.

Model (b) highlights the potential influence of culture on the MNL. The model is like that of a coordination system with a horizontal axis and a vertical axis. Such an MNL may be developed and reinforced by western measurements such as “meters”, where smaller magnitudes are represented on the left side of space and larger magnitudes are represented on the right side of space. Moreover, the practice of weaving may reinforce such an MNL. Mentally planning and counting weaving pattern in a coordinate system would be beneficial to ensure symmetry (Fischer, 2010). Additionally, such an MNL is susceptible to the inclusion of negative numbers. As has been briefly reviewed, there is a discussion weather the MNL includes negative numbers (Zhang & You, 2012; Fischer & Shaki, 2017). When assuming that they are represented on the MNL, then they could map onto the left space of the horizontal axis of model (b).

The Role of Numerical Classifiers

Authors note that classifier systems may take a long time to memorize due to the large amount of numerical classifiers existing in the languages of the Admiralty Island. Classifier systems may therefore be acquired into the language after serial counting numerals are (Blust, 2021i). Following this hypothesis, it might be that an MNL based on serial counting numerals is established first. When numerical classifiers are acquired into language and memory they may perhaps A) Be mapped onto the MNL as versions of serial counting numerals or B) Be map onto the MNL but as numbers independent from serial counting numerals. Such a prediction is possible if the MNL is flexible and if its start and endpoint is dependent on the numbers being judged in the situation, as is argued by researchers (Schiller et al., 2016).

The hypothesis that numerical classifier systems are based on a serial counting numeral MNL is supported by the notion that numerical roots are incorporated into the classifier words. For some languages, these numerical roots are almost identical to the serial counting numerals. For instance, in Loniu the numerical root for 5 is *lime* and the serial counting numeral is *malimeh.* The classifier words in Loniu employ the prefix *ma* + numerical root + classifier*,* where prefix *ma* is used as an indication of something being counted. To illustrate, *malimecan* consists of the prefix *ma*, the numerical root for 5 *lime* and the classifier *can* which is used for counting roads, paths and boundaries. *Mahakap* uses the prefix *ma,* the numerical root for 4 *ha* and the classifier *kap* which is used for counting the leaves of plants (Hamel, 1994; Blust, 2021i). Because the numerical roots resemble that of serial counting numerals, it may be that they map onto the MNL as versions of serial counting numerals.

However, if numerical classifier words are perceived as independent from the words of serial counting numerals, then they may be represented as own entities on the MNL. When such is the case then the discussed characteristics related to dimensions, scale and range still apply. The MNL may be shaped as those depicted in Figure 3 for serial counting numerals, where the numbers are adjusted to specific classifiers. For instance, when counting houses in Lele the word *hum* is used. One house is *hum,* two houses is *ma-r-hum*, three houses is *ma-til-hum*, four houses is *ma-ha-hum* and so on (Boettger, 2015). These words may replace the serial counting numbers in the model when operating with nouns connected to a classifier.

Conclusions and Closing Remarks

This study investigated possible mental representations of numbers in individuals using the counting systems on the Admiralty Islands. The aim of the study was to contribute to the theoretical knowledge on mental number lines in relation to culture. Counting systems were collected for 25 languages and 1 dialect of the Admiralty Islands (shown in Table 1). The characteristics of the counting systems predicted an MNL of linear scale of two-dimensions ranging from 1 to 100. Two MNL models were suggested based on the characteristics (depicted in Figure 3). The first model highlighted the possibility of numbers as "building blocks". The blocks combined can produce larger numbers (inspired by Bender & Beller, 2011). The second model highlighted the influence of cultural measurements and tools to create an MNL similar to that of a coordination system (inspired by Fischer, 2010).

There are some limitations to the present study that need to be acknowledged. First, authors were in disagreement in the report of some number words. The literature with the most descriptive number system was chosen for further inclusion when this was the case. Although similar reported number words across literature would have strengthened the validity of the study, it is important to consider that language is continuously developing and changing. Thus, disagreeing number words may be a result of when numerical data in the studies were obtained. On that note, many of the studies used for the present study are written several years ago. This threatens the legitimacy of the results, as the conclusions drawn may be outdated. Recent fieldwork on number systems on the Admiralty Islands are nevertheless in short supply.

There is a need for investigation of how culture affects mental representations of numbers. Cross-cultural research, such as the current study, is important for achieving a full picture of these representations. While there are some studies done on numbers and language for western participants (e.g., Pasqualotto et al., 2014), less studies are done with non-western participants. Thus, the data collected, the conclusions made and the presented models should be considered for future studies. No hypotheses were tested as this thesis employed a theoretical approach. The next step for future studies would thus be to test the predictions made empirically. When such steps are taken, we may be one step closer to discovering how counting systems and mental representations are interacting. As outlined, the MNL may have implications for arithmetic abilities (Park & Brannon, 2013, Li et al., 2018). In a broader perspective, numerical cognition has been argued as important for successful outcomes in both social and economic domains (Rubensten, 2016), as well as for the facilitation of mnemonic memory processes and cognitive control (Menon, 2016).

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Appendix A: Villages and Islands of the Admiralty Islands

Manus, Los Negros, Wuvulvu, Aua, Pitylu, Ndrilo, Sisi, Bipi, Lou, Pak, Tong, Ninigo, Hermit, Ponam, Rambutyo, Nauna, Baluan, Sori, Harengan, Andra, Hus, Pam, Hauwei, Pomassau, Chalalou (Selalou), Mbuke (M`Bunai), Timoenai, Mouk, Papitalai, Sonilu, Nohang, Yiru, Drabito, Pau, Metawari, Bowat, Tingau, Koruniat, Derimbat, Lowa, Patu, Lala, Peli, Nyada, Lessau, Nihon, Kali, Kogo, Leihuwa. Likum, Drehet, Tulu, Bundralis, Nohuai and Pelipowai (Healey, 1976, pp. 356–357).

Appendix B: Sources of Numerals in Table 1 and Some Classifiers

Language(s)	Source(s)	Numerical Classifiers
Proto–Oceanic	Bender, A. & Beller, S. (2011). Cultural variation in numeration systems and their mapping onto the mental number line. *Journal of cross- cultural psychology, 42*(4), 575–597. https://doi.org/10.1177/0022022111140663	
Andra	Smythe W. E. & Z´graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* pp. 183-188. Summer Institute of Linguistics.	
Hus	Smythe W. E. & Z´graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* pp. 183-188. Summer Institute of Linguistics.	
Lele	Boettger, J. (2015). *Topics in the grammar of Lele: a language of Manus Island, Papua New Guinea* [Doctoral Thesis, James Cook University], pp. 190–191. ResearchOnline@JCU.	(p. 195): money, humans, houses, villages, roads. groups of trees, canoes, knives etc.
Koro	Cleary–Kemp, J. (2015). *Serial verb constructions revisited: a case study from Koro* [Doctoral Thesis, University of California, Berkeley], p. 16. ProQuest.	(p. 16): people, trees, houses, baskets, buts, cups.

Titan	Owens, K., Lean, G., Paraide, P. & Muke, C. (2018). *History of Numbers,* pp. 99, 156. Springer. https://doi.org/10.1007/978-3-319-45483-2 Smythe W. E. & Z′graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	
Ere	Owens, K., Lean, G., Paraide, P. & Muke, C. (2018). *History of Numbers,* p. 321. Springer. https://doi.org/10.1007/978-3-319-45483-2	
Kele	Owens, K., Lean, G., Paraide, P. & Muke, C. (2018). *History of Numbers,* p. 322-324. Springer. https://doi.org/10.1007/978-3-319-45483-2	(p. 323): animates, houses buildings, long objects, actions involving the voice, spears, rivers etc.
Leipon	Smythe W. E. & Z′graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* pp. 183-188. Summer Institute of Linguistics.	
Ponam	Owens, K., Lean, G., Paraide, P. & Muke, C. (2018). *History of Numbers,* p. 313-314. Springer. https://doi.org/10.1007/978-3-319-45483-2	In Owens (2018, p. 314): Parts, bundles, bags, blades, strings of objects, fish, hooks, persons, holes, nets, sails.

	Carrier, A. (1981). Counting and calculation on Ponam Island. *Journal of the Polynesian Society, 90*(4), 465–479.	
Loniu	Hamel, P. J. (1994). *Grammar and Lexicon of Loniu, Papua New Guinea.* Pacific Linguistics, the Australian National University. https://doi.org/10.15144/PL-C103.cover	Tree/wood, rope, leaf, betel nut, fish etc.
Mokerang	Smythe W. E. & Z´graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	
Pak	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 7: Pak. *Language and Linguistics in Melanesia,* 486.	
Bipi	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 2: Bipi. *Language and Linguistics in Melanesia,* 99-100.	(p. 101): betel nuts, coconut
Hermit	Smythe W. E. & Z´graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	

Nyindrou	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 3: Lindrou. *Language and Linguistics in Melanesia,* 173.	
Sori	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 4: Sori. *Language and Linguistics in Melanesia,* 238-239.	(p. 239 – 240). Child, house, fish.
Levei (Khehek dialect)	Blust, R. (2013). *The Austronesian languages,* p. 280. Asia – Pacific Linguistics. Smythe W. E. & Z′graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	
Likum	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 5: Likum. *Language and Linguistics in Melanesia,* 297.	(p. 298–299): houses, pigs, children, trees, leaves, coconuts, fish.
Tulu	Smythe W. E. & Z′graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	
Paluai	Schokkin, G. H. (2014). *A grammar of Paluai: the language of Baluan Island,*	(p. 96, 159): animates, inanimates. trees,

	Papua New Guinea [Doctoral Thesis, James Cook University]. ResearchOnline@JCU	bunches of round fruits, heaps of stomes, yam etc.
Nauna	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 8: Nauna. *Language and Linguistics in Melanesia,* 546-622.	
Penchal	Blust, R. (2013). *The Austronesian languages,* p. 280. Asia – Pacific Linguistics.	
Kaniet	Smythe W. E. & Z´graggen, J. (1975). *Comparative wordlist of the Admiralty Islands languages,* p. 183-188. Summer Institute of Linguistics.	
Seimat	Blust, R. (2021). Eight languages of the Admiralty Islands, Papua New Guinea: sketch 1: Seimat. *Language and Linguistics in Melanesia,* 23-24.	(p. 24 – 26): people, trees, animals.
Wuvulu–Aua	Owens, K., Lean, G., Paraide, P. & Muke, C. (2018). *History of Numbers,* p. 101. Springer. https://doi.org/10.1007/978-3-319-45483-2 Hafford, J. A. (2015). *Wuvulu grammar and vocabulary* [Doctoral Thesis, University of Hawai´i]. ProQuest.	

Kurti	Fischer, J. (2010). *Enriching students´ learning through ethnomathematics in Kuruti elementary schools in Papua New Guinea.* ResearchGate.	nuts and fruits, houses and huts, animates, trees, logs and sticks, leaves and ears, days, pools of water etc.