# Methods

## Participants

Thirty-three participants (26 females, age 19-41 years, mean age 23.4 years; 7 males, age 20-36 years, mean age 25.0 years) took part in the experiment. We excluded 11 participants from the analysis as they failed to complete the experiment or made no response in at least one block. As this was an online experiment, we expected dropouts, but we believe there was no self-selection bias with respect to participants perception of words, therefore, the data is missing completely at random. The resulting sample consists of 22 participants (16 females, age 19-41 years, mean age 23.7 years; 6 males, age 20-36 years, mean age 25.7 years). The online repository contains data for all participants with exclusion criteria and a list of excluded participants coded in the analysis script for the sake of replicability of our analyses.

Participants were recruited through advertisements posted around the University of Bamberg and were instructed to participate in the experiment only if they spoke German at a native level to fulfill the requirements to deeply understand the German homonyms in the entire range of meanings. All procedures were in accordance with the national ethical standards on human experimentation and with the Declaration of Helsinki of 1975, as revised in 2008. The study was in full accordance with the ethical guidelines of the University of Bamberg and was approved by an umbrella evaluation for psychophysical testing of the university ethics committee (Ethikrat) on 18 August 2017. Informed consent was obtained from all observers prior to each experimental session. All participants had normal or corrected-to-normal vision and normal color vision, all tested by standard tests in situ, and were naïve to the purpose of the study. For their participation, observers received course credit within the framework of a mandatory module of research participation in accordance with the standards of the University of Bamberg.

## Material

The second author created the material. We selected five German words that were assumed to be unambiguous (**Table 1A**) and twenty polysemic words expressing different meanings. Out of these twenty polysemic, fifteen words had two primary meanings (**Table 1B**), and five had three primary meanings (**Table 1C**). In addition, the word "Blatt," which can mean either "Laubblatt" (a leaf) or "Blatt Papier" (a sheet of paper), was used as an example in instructions and during the first training block and was excluded from the analysis.

Table 1. Words used in the study, their assumed meaning(s), and translation to English (in blue). Word frequencies are reported on a scale from 1 (rare) to 6 (frequent) (*DWDS*, 2023)

|  |  |  |  |
| --- | --- | --- | --- |
| **Word German** | **A) Words with single meaning (German | English)** | | **Word frequency** |
| Brief | geschriebene Nachricht | Letter | 4 |
| Gedicht | lyrische Dichtung | Poem | 3 |
| Lampe | Beleuchtung | Lamp | 3 |
| Mensch | Person | Person | 5 |
| Sessel | gepolsterter Stuhl | Armchair | 3 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Word** | **B) Words with two meanings (German | English)** | | | | **Word frequency** |
| Schloss | Palast | castle | Verschluss | lock | 4 |
| Sprosse | Querholz einer Leiter | rung | Pflanzentrieb | sprout | 2 |
| Kiefer | Kieferknochen | jaw | Baum | pine | 3 |
| Absatz | Stöckel | heel | Abschnitt | paragraph | 3 |
| Gericht | Tribunal | court | Essen | meal | 4 |
| Pension | Rente | pension | Gasthaus | guesthouse | 3 |
| Schale | Äußere Schicht von Obst | peel | Schüssel | bowl | 3 |
| Linse | Kameralinse | lens | Linsenpflanze | lentil | 3 |
| Hahn | Gockel | rooster | Wasserhahn | faucet | 3 |
| Strauß | Vogel | ostrich | Blumenstrauß | bouquet | 3 |
| Ball | Spielzeug | ball | Tanzveranstaltung | prom | 4 |
| Bar | Lokal | bar | Einheit | unit | 3 |
| Pflaster | Verband | band aid | Straßenbelag | cobble stone | 3 |
| Mutter | Mama | mother | Schraubenmutter | nut | 4 |
| Gut | Positiv | good | Besitz | estate | 4 |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Word** | **C) Words with three meanings (German | English)** | | | | | | **Word frequency** |
| Messen | Maß nehmen | to measure | Gottesdienste | masses | Ausstellung | fairs | 4 |
| Decken | Federbetten | blankets | Zimmerdecken | ceilings | Tisch decken | set the table | 3 |
| anstellen | Anreihen | to wait in line | Einstellen | to hire someone | Empfindlich sein | to be touchy | 3 |
| Mine | Bergwerk | (coal) mine | Sprengkörper | explosive device | Bleistiftmine | lead | 3 |
| Schuppen | Bretterhäuschen | shed | Fischschuppen | Scales | Haut-schuppen | dandruffs | 2 |

## Apparatus and Procedure

The experiment was conducted online using custom software. For each word, participants were presented with key mapping between cursor keys and meanings of the word. A single d*own* key was used to map the meaning for words with a single meaning, *left* and *right* keys for words with two meanings (**Figure 1**), and *left, down,* and *right* keys were used for words with three meanings. The participants were instructed to use *up* key for an additional meaning that was not listed. Furthermore, the *space* key indicated that the word expressed no meaning to the participant.

Graphical user interface

Description automatically generated with medium confidence

Figure 1. On-screen instructions on meaning-key mapping for word *Bar*.

The experiment consisted of 26 runs, including the first training run. Apart from the first training block that always used the word "Blatt," the word order was fully randomized. The 25 test trials corresponded to the words in Table 1. Participants started the run by pressing the "Enter" key. A respective audio recording was played 30 times during each run, repeating every two seconds. The duration of individual audio recordings was less than 2 seconds but depended on the length of the word. The shortest recording was for the word "Ball" (0.33 s), whereas the longest one was for the word "anstellen" (0.9 s). The average recording duration was 0.64±0.14 s (mean and standard deviation). A single run lasted approximately 60 seconds but for timing imprecision and delays when initiating audio playback in the browser. Participants responded by continuously pressing one of the allowed keys (see above).

## Data analysis

Statistical analysis was performed in R 4.1.1 (R Core Team, 2022) using the *tidyverse*family of packages (Wickham et al., 2019). The online repository contains complete data set (see below). We excluded 11 participants who failed to complete the experiment or made no response in at least one block (see above). Applying these outlier criteria, we performed analyses on 22 out of 33 participants' data sets. Unless stated otherwise, we used median and interquartile range statistics to summarize the dominance of individual meanings.

## Open Practices Statement

The auditory stimuli, the complete data set and the analysis code under Creative Commons Attribution 4.0 International Public License at <https://osf.io/jm8ge/> or <https://github.com/alexander-pastukhov/multistable-homonyms>.

# References

*DWDS – Digitales Wörterbuch der deutschen Sprache. Das Wortauskunftssystem zur deutschen Sprache in Geschichte und Gegenwart.* (2023). Berlin-Brandenburgischen Akademie der Wissenschaften. https://www.dwds.de/

R Core Team. (2022). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T., Miller, E., Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686