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ON THE NUMBER OF HANDEDNESS GROUPS

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SUMMARY

There is a considerable debate among laterality researchers with respect to whether handedness is a continuous or categorical trait, and if the latter, how many handedness groups should be distinguished. This study addresses a statistical test of this issue. Finite mixture modelling was used to determine the number of handedness groups based on handedness data. Two datasets are used to present differences between the healthy population and patients with PD. Three handedness groups can be distinguished in both populations; however, the pattern of handedness is clearly different in patients with Parkinson's disease.

Key words: Finite mixture modelling, latent class analysis, handedness, Parkinson's disease

INTRODUCTION

The current debate on handedness includes a discussion of whether this characteristic is a categorical or continuous variable. The genetic models of handedness proposed by leading scientists reflect the uncertain nature of this trait. For example, the model by Annett proposes a continuous nature of handedness, whereas McManus' model is based on the assumption of a categorical nature of handedness.

Handedness is assessed as either a preference or skill/performance (we use performance from this point forward). Self-administered items that measure hand preference usually exhibit bimodal distributions. These items are often scored using two categories (*use the right hand* or *use the left hand*), three categories (*use the right hand*, *use both hands equally often*, or *use the left hand*), four categories (*always use the right hand*, *prefer to use the right hand*, *prefer to use the left hand*, or *always use the left hand*) or five categories (*always use the right hand*, *prefer to use the right hand*, *use both hands equally often*, *prefer to use the left hand*, or *always use the left hand*). The situation becomes more complicated when the actual performance of the hands is taken into account. The

superiority of one hand in terms of performance items is expressed as either a difference score (R−L) or standardised difference score (R−L)/(R+L). Certain tasks (i.e., peg-moving) exhibit nearly normal unimodal distributions , supporting Annet's view of continuous handedness. Other tasks, such as putting dots in circles have bimodal distributions, implying two discrete categories of individuals. These distributions are analogous to the two modes observed in hand preference measures.

It is also argued that the unimodal distribution of peg-moving is due to the smaller dependency of this task on asymmetric processes, such that the modes converge, one being subsumed within the other. Thus, this apparently unimodal distribution would actually be a mixture of two normal distributions.

Recent studies using statistical models support the categorical nature of handedness, but the bimodality of hand preference is not supported. The study by Dragovic, who used the Edinburgh Handedness Inventory, demonstrated that there are three handedness categories in the healthy population: right-handed individuals, left-handed individuals and mixed-handed individuals. The subsequent cross-validation study performed using the Annett's Hand Preference Questionnaire confirmed that the three classes solution best fits the data, with the following percentages of class membership: "consistent right" (66.0%), "consistent left" (9.8%) and "inconsistent or mixed" (24.2%).

Different distributions of handedness can be observed in individuals with diseases based on impaired dopaminergic pathways, such as schizophrenia or neurodegenerative syndromes. Excessive percentages of left- and mixed-handed individuals have been observed in patients with schizophrenia, autism, attention-deficit/hyperactivity disorder, mental retardation, or other psychotic problems.

Parkinson's disease (PD) belongs the family of diseases in which the dopaminergic pathway is affected, but no excessive proportion of left-handed individuals has been observed in this population. However, clinical practice and the results of previous study suggest that patients tend to change their preferred hand when the PD symptoms are more pronounced on the preferred limb. Given the distribution of handedness, it is expected that right-handed individuals will switch their preferred hand more frequently, and therefore, that a higher proportion of left-handed individuals or mixed-handed individuals would be observed in the PD population.

This study aimed to (i) investigate how many latent handedness groups are described by our healthy and PD population datasets and (ii) interpret and compare the handedness groups present in both populations.

SAMPLE AND METHODS

Sample and measures

Two datasets collected between 2008 and 2010 and described below in detail are used in this study.

- ***Sample patients with Parkinson's disease***

This sample consisted of 683 patients with PD seen at the Prague Movement Disorders Center between June 2006 and February 2007. All subjects provided informed consent. The data collection was approved by the local human studies committees.

The response rate among the 683 patients was 77% (523); 52 were excluded prior to the analyses due to incomplete or inconsistent responses. Thus, data from 471 PD (69%) patients were analysed (276 men and 195 women). The mean age of the patients was 66.5 (SD = 9.3) years, and the mean duration of the disease was 10.0 (SD = 6.1) years.

The data from the patients with PD were collected using a 7-item handedness questionnaire, which was part of a larger survey (27 items) on laterality in PD. The other items included in this survey concerned individual preferences of the legs, eyes and ears. However, these items were not included in the analyses because this study focuses on handedness only. Because there is no standardised handedness questionnaire for PD, the items for handedness were taken from previously standardised tools, such as the Edinburgh Handedness Inventory or Annet's laterality questionnaire. These items have been independently assessed and validated by four neurologists, two kinanthropologists and a two psychometricians experienced in the design of questionnaires for use in patients with PD. This resulting 7-item hand preference questionnaire had an internal consistency of 0.90 and factor validities that ranged from 0.56 to 0.95.

The patients were asked which hand they preferred prior to the onset of the signs of PD. They were also asked about which hand they currently preferred for specific motor activities, such as *handwriting*, *hairdressing*, *holding a toothbrush*, *holding a spoon*, *unlocking a door*, *knocking on a door*, and *cutting with a knife*. The responses were recorded on a 5-point scale (1 = always use the right hand, 2 = prefer to use the right hand, 3 = use both hands equally, 4 = prefer to use the left hand, and 5 = always use the left hand).

- ***Sample of healthy individuals***

The dataset analysed here was composed of the responses of 2055 individuals who completed an online questionnaire. Of these, 529 (25.7%) were excluded due to incomplete or apparently invalid responses, e.g., random responses or responses with no variability. The analysed sample comprised the remaining 1526 (868 females, 584 males, and 74 unknown) respondents from 97 countries. The mean age of respondents was 33.0 years (SD = 12.8 years). Given the online nature of the research and voluntary participation of the respondents, no consent was signed by the respondents.

An online questionnaire (available at https://www.surveymonkey.com/s/T8LXXSZ) was developed in 3 languages (English, Czech, and Chinese). This computer-based survey included 4 items that measured handedness (*holding a toothbrush*, *hammering a nail*, *throwing a ball*, and *unlocking a door*). These items were chosen because they are appropriate for individuals of all known cultures (unlike, for example, writing). Furthermore, these items make sense within the context of several adaptive theories on the origin of laterality. These four handedness items are used here to evaluate the level of measurement of hand preference scores.

The handedness responses were recorded on 5-point scales, with the responses arranged in the following manner: always use the right hand = 1, prefer to use the right hand = 2, use both hands equally often = 3, prefer to use the left hand = 4, and always use the left hand = 5.

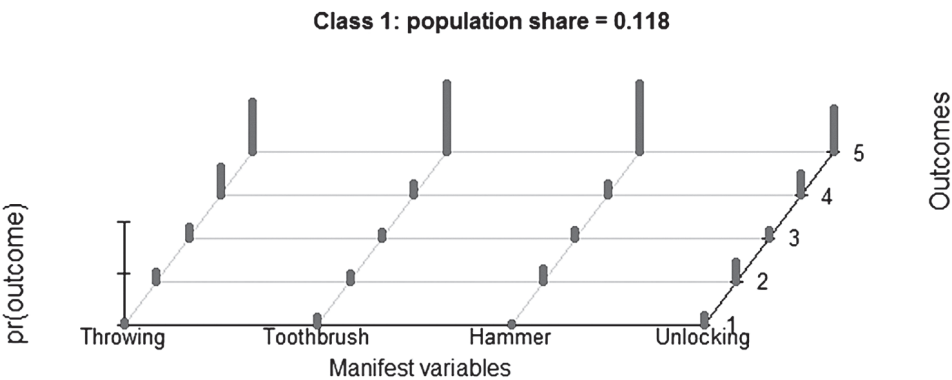
Analysis

A finite mixture modelling approach (i.e., latent class analysis (LCA)) was used to examine and interpret the handedness groups described by the responses to the preference-based handedness questionnaires. The analyses were performed in R using LCA routines in the "poLCA" library. Although it is common practice to present only the final and best-fitting model, we believe that clustering under different numbers of classes may provide insight into the clustering of the respondents into different numbers of handedness groups. Therefore, we present models for 2, 3, 4 and 5 classes. These analyses are followed by the assessment of a model fit for which we used Akaike's information criteria (AIC) and Bayesian information criteria (BIC).

RESULTS

The 2-class model

Figure 1 illustrates the probability of the respondent's answers to the response categories for each item. This figure also illustrates the allocation of the respondents to each class.



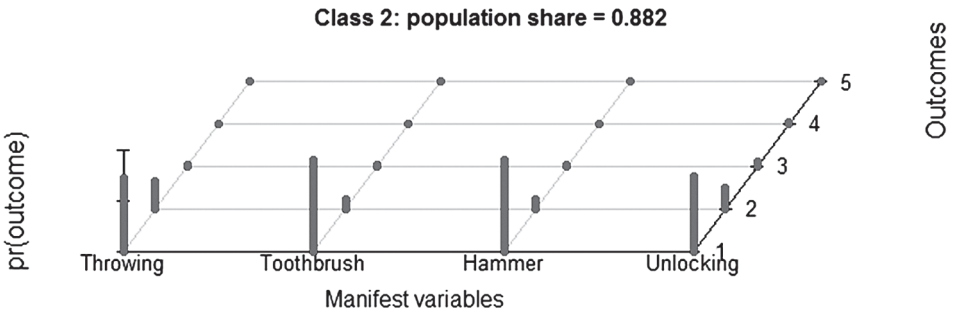


Figure 1. The 2-class solution for the healthy population

Of our sample, 11.8% are allocated into the first class, which has the highest probability of responding with response category 5 (i.e., "always use the left hand"). This class therefore consists of left-handed individuals. The second class consists of 88.2% of the respondents. This population was most likely to respond with category 1 (i.e., "always used the right hand"), thus being right-handed individuals. The proportions of both groups strongly reflect the distribution of handedness in the population.

Under the 2-class model, the situation differed for patients with PD compared with the healthy population. In this model, 75.3% are right-handed individuals (see Figure 2), i.e., less than in the healthy population. The second class, with a proportion of 24.7%, exhibit no clear handedness. In the literature, this population is occasionally denoted as mixed-handed or non-right-handed.

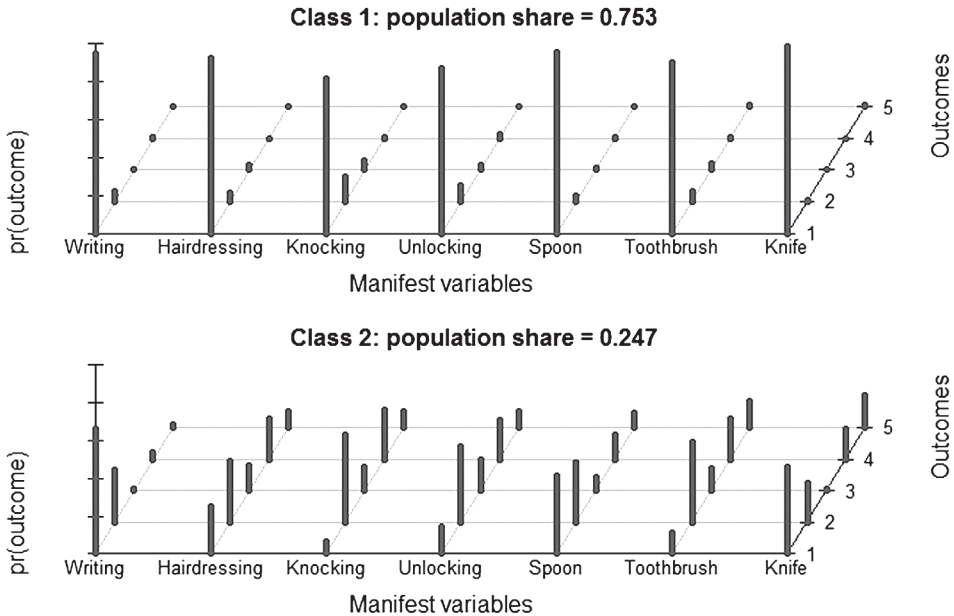


Figure 2. The 2-class solution for the PD population

The 3-class model

The conditional probabilities for the 3-class model for the healthy population are illustrated in Figure 3. In this model, 9.7% of the participants are left-handed individuals, 16.5% of the participants are mixed-handed individuals (or rather weak right-handed individuals; see conditional probabilities for class 2). Class 3 (consistent right-handed individuals) comprises 73.9% of the sample.

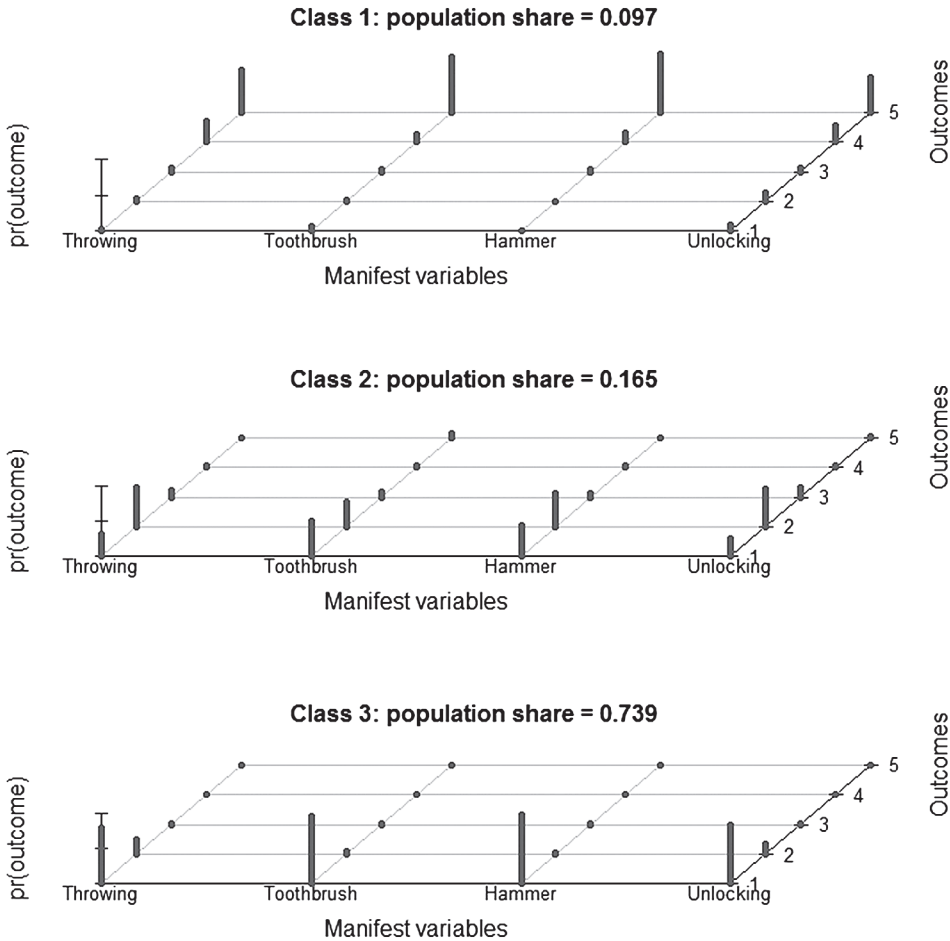


Figure 3. The 3-class solution for healthy population

The 3-class model for PD (Figure 4) consists of a group of consistent right-handed individuals (class 3, comprising 65.8% of the sample), weak right-handed individuals (class 1, 22.7%) and weak left-handed individuals (class 2, 11.5%). Interestingly, weak left-handed individuals prefer to use the right hand for writing and to certain extent, holding a spoon.

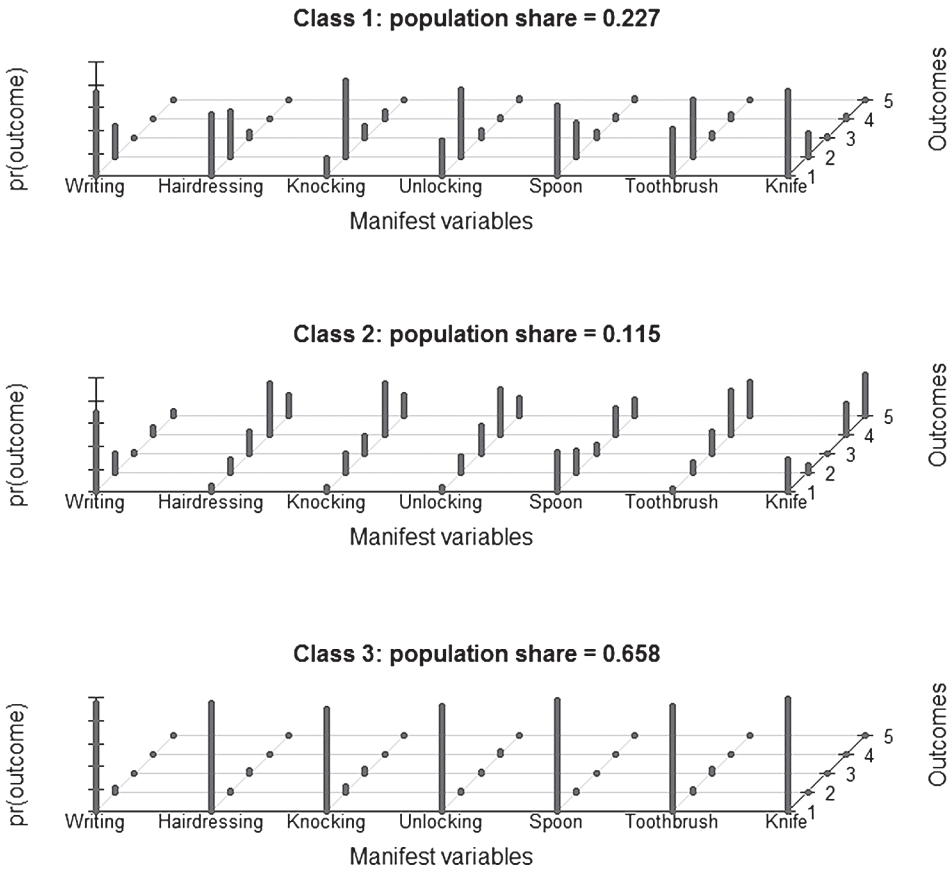


Figure 4. The 3-class solution for the PD population

The 4-class model

Adding another class to the 3-class solution leads to the results illustrated in Figure 5 (for healthy individuals) and Figure 6 (for the PD population). The proportions of the 4 classes among the healthy individuals are as follows: right-handed individuals (class 2, 66.1%), weak right-handed individuals (class 1, 21.4%), mixed-handed individuals (class 3, 3.8%) and left-handed individuals (class 4, 8.7%).

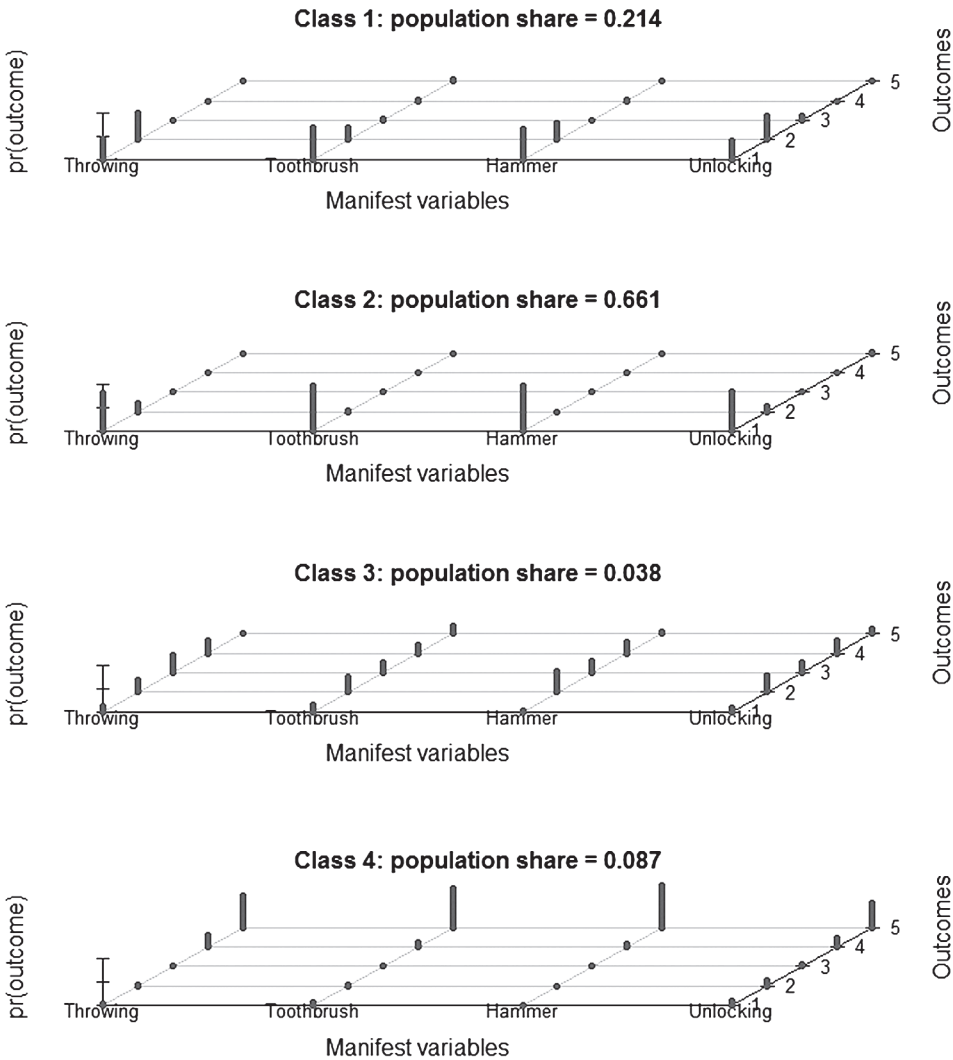


Figure 5. The 4-class solution for the healthy population

For the PD population, the results are somewhat different. Class 2 and class 4 exhibit very similar conditional probabilities and are therefore difficult to distinguish from a substantive perspective. Both of these classes may be classified as weak left-handed individuals and together comprise 7.9% of the sample. With respect to the 3-class solution, we again observe a preference among left-handed individuals for using the right hand when writing and holding a spoon. The other two classes are similar to the 3-class solution; class 1 consists of right-handed individuals (66.4%), and class 3 consists of weak right-handed individuals (25.8%).

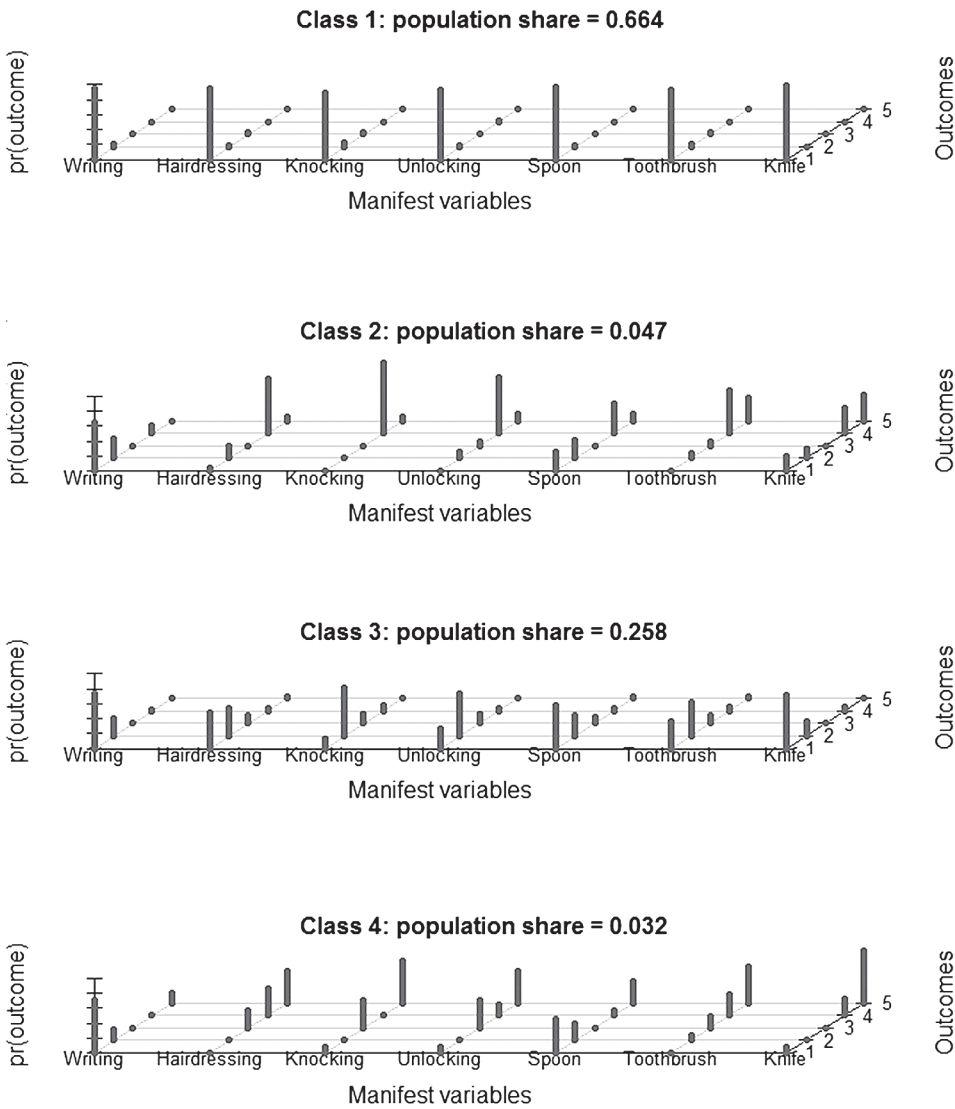


Figure 6. The 4-class solution for the PD population

The 5-class models

Finally, we present a 5-class model for both datasets. The healthy population is illustrated in Figure 7. Class 1 (45.9%) and class 3 (23.4%) are difficult to distinguish from a substantive perspective as both classes consist of strong right-handed individuals. Class 2 consists of weak right-handed individuals (18.2%). Mixed-handed individuals constitute class 4, with a proportion near 4%. The proportion of left-handed individuals (class 5) was 8.7% of the population.

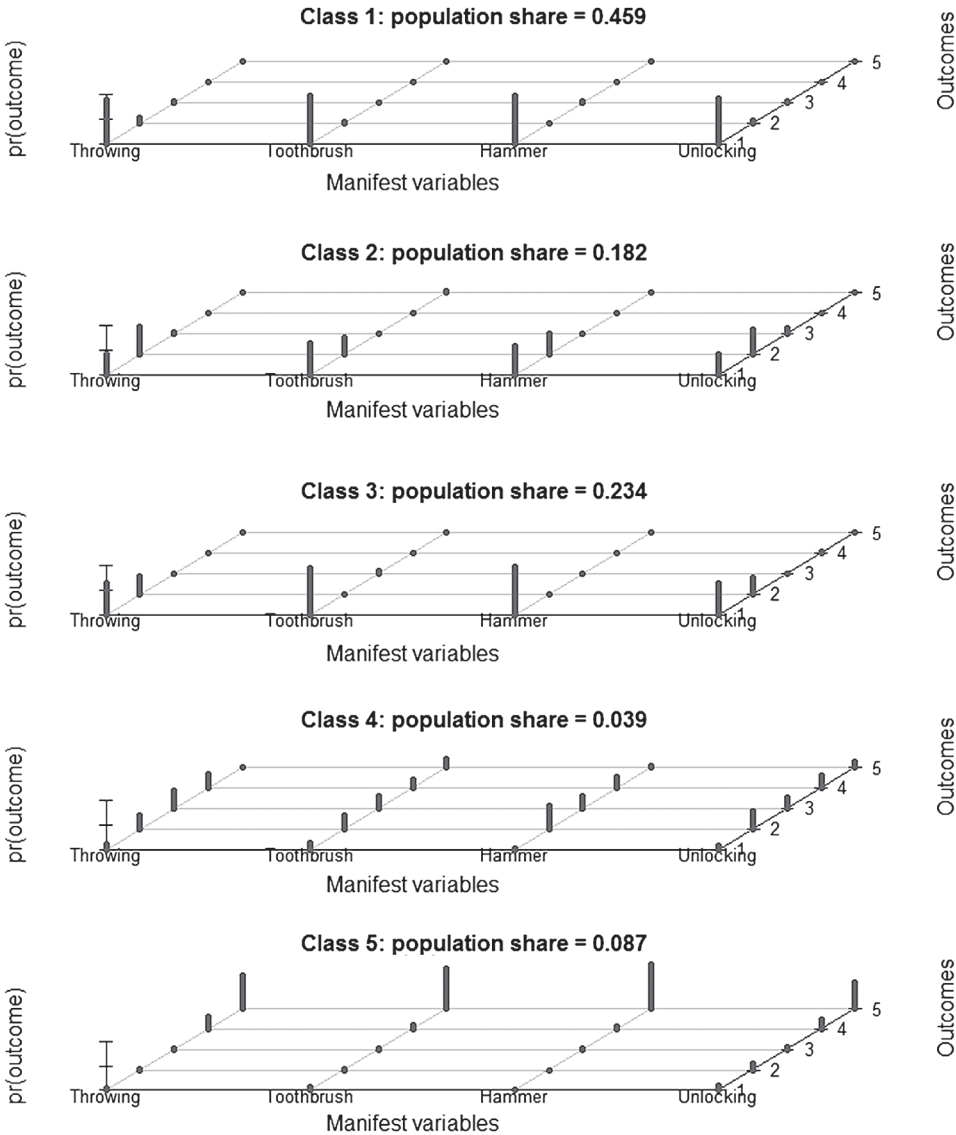


Figure 7. The 5-class solution for healthy population

The same model for the PD population suggests that three out the five classes that are presented in Figure 8 are composed of right-handed individuals (those in class 1 [21.1%] and 4 [56%] are strong right-handed individuals, and those in class 5 [12.8%] are weak right-handed individuals). Class 3 consists of mixed-handed individuals (3.4%), and class 2 consists of weak left-handed individuals (6.7%). Again, weak left-handed individuals and mixed-handed individuals prefer to write and hold the spoon with the right hand. In addition, mixed-handed individuals have a higher probability of using the right hand for holding a knife when cutting bread.

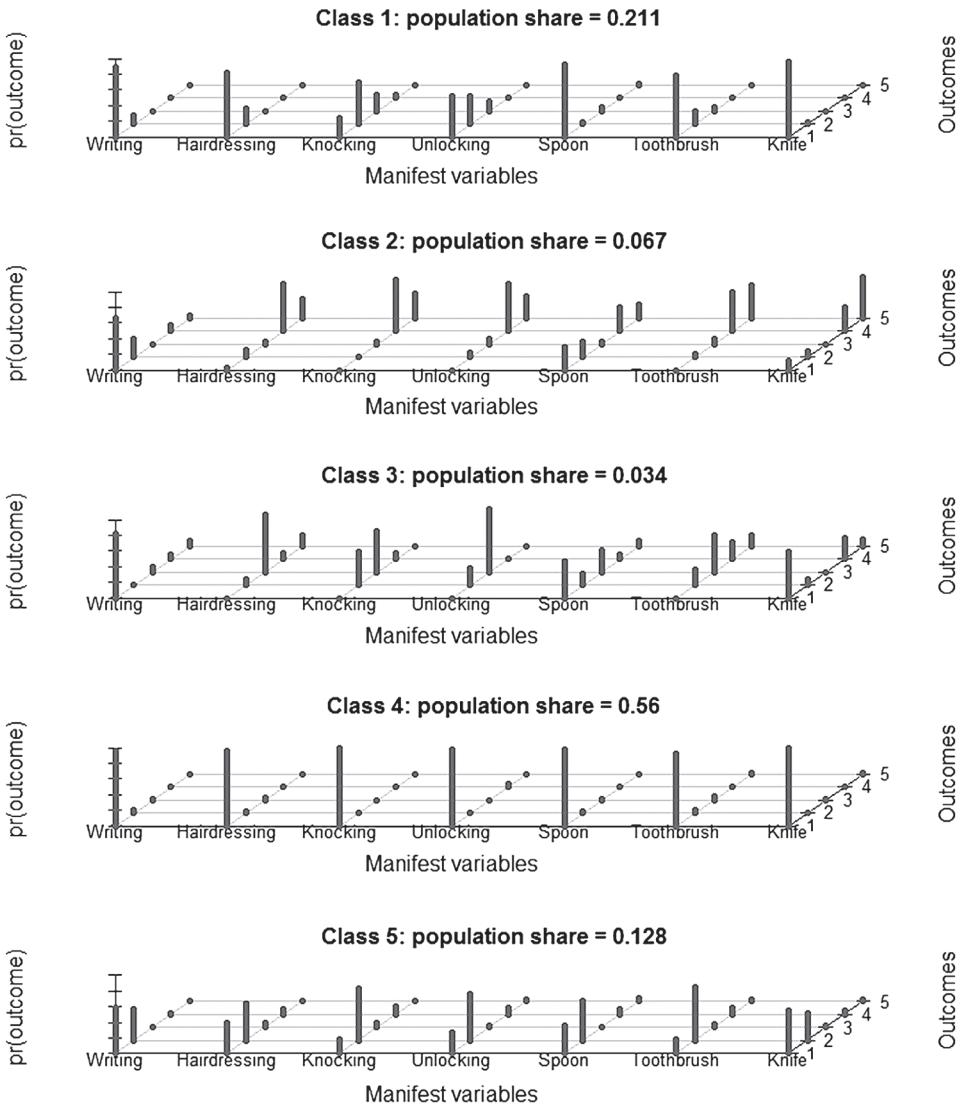


Figure 8. The 5-class solution for the PD population

Models with 6 or more classes

It is possible to use models with more than 5 classes. However, the results suggest that the addition of more classes leads to difficulties in the interpretation of certain classes, and the classes make less sense from a substantive perspective. In addition, more classes require larger sample sizes, and the estimates are therefore less trustworthy. For these reasons and the sake of brevity, such models are not presented here. However, fit indices for 6-class models are presented in the following section.

Assessment of model fit

I presented 2-, 3-, 4-, and 5-class models for both healthy and PD populations. All of the models are substantially meaningful. The fit indices can be used to suggest which model fits the data from a statistical perspective. Akaike's Information Criteria (AIC) and Bayesian Information Criteria (BIC) can be used to this end, and these criteria are shown in Table 1. Model with the smallest value of the corresponding fit index within each sample fits the data best. Fit indices for 6-class models are also included.

Table 1. Fit indices for LCA models

	PD population					Healthy population				
	2-class	**3-class**	**4-class**	**5-class**	**6-class**	**2-class**	**3-class**	**4-class**	**5-class**	**6-class**
AIC	4185.1	3983.9	3972.2	**3945.4**	3969.9	9032.0	8715.1	8652.7	**8639.4**	8654.1
BIC	4417.8	**4334.9**	4441.6	4533.3	4676.1	9207.9	**8981.6**	9009.8	9087.2	9192.5

Regardless of the sample used in the analysis, the AIC indices suggest that the 5-class solution best fits the data, whereas the BIC indicate that the 3-class solution is better. Given that (i) the 5-class solution makes less sense from a substantive perspective (two classes within the model have substantively the same interpretation); (ii) the 5-class solution is less parsimonious than the 3-class solution; and (iii) the BIC are better suited for the purposes of our study (see Discussion), we prefer the 3-class solution.

DISCUSSION

This study aimed to identify how many latent groups underlie the data obtained from handedness questionnaires. The use of two different samples (a healthy population and PD population) allows (with certain limitations discussed below) for a comparison of the results for both populations. A finite mixture modelling approach was used to identify the latent groups.

The fit of the model was assessed using the AIC and BIC. The BIC favour a 3-class model, whereas the AIC favour a 5-class solution. Because the AIC are asymptotically equivalent to cross-validation, they are more useful for prediction. However, the goal of our analysis was not prediction but explanation and description. The BIC are more suitable for explanatory purposes because they allow for consistent estimation of the

underlying data-generating process. In addition, the BIC penalise to a greater extent for extra parameters and thus favour more parsimonious models than the AIC. We therefore prefer the solution suggested by the BIC.

A 3-class model is preferred for the healthy population for both statistical and substantive reasons. This result confirms the findings from previous studies. The percentage of left-handed individuals (9.7%) is close to the value of 9.8% observed in Dragovic & Hammond. However, the same study reported the proportion of mixed handedness to be slightly higher (24.2%) compared with the 16.5% presented here. Moreover, the number of consistent right-handed individuals reported by Dragovic & Hammond is lower (66%) compared with our findings (73.9%). These differences can partly be explained by the smaller sample used by Dragovic & Hammond. Another explanation is that in our sample, mixed-handed individuals can be better described as weak right-handers rather than truly ambidextrous individuals, which was the classification used in Dragovic & Hammond.

The data from the PD population also support a 3-class solution. The distribution of individuals belonging to each class is, however, different compared with that observed for the healthy population. A smaller percentage of right-handed individuals and higher percentages of mixed- and left-handed individuals were observed in the PD population. In addition, the class of left-handed individuals in the PD population exhibit less extreme left-handedness than the same class in the healthy population. We argue that these facts may suggest influence of PD on handedness of patients. This statement is not supported by previous studies, which have reported similar handedness distributions for patients with PD and healthy populations. However, a higher percentage of non-right-handed individuals may be compensated for by the known decrease in the proportion of left-handed individuals in the older population, from which patients with PD are generally recruited.

Interestingly enough, a detailed examination of the conditional probabilities in Figure 4 reveals that the class of left-handed individuals in the PD population still prefers to use the right hand for writing. A somewhat similar (but less pronounced) result can be observed for holding a spoon. These findings can be explained by the cultural specificity of the Czech Republic. The vast majority of the patients from our PD sample were born before 1960. According to the legislation effective in this country till 1967, children born left-handed were forced to use the right hand in school (where the primary activity is writing and eating in school cafeterias). This factor also indicates a potentially problematic validity of the item *writing* in laterality questionnaires in certain cultures.

One of the limitations of the presented study was that different items (with respect to content and number) were used for both samples. However, this only slightly limits the comparison of both samples because (i) all of the items used in this study are valid items for handedness assessment and (ii) both sets of items exhibited the unidimensionality required for latent class analysis, as demonstrated in Štochl.

ACKNOWLEDGEMENTS

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REFERENCES

ANNETT, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology*, 61(3), pp. 303–321.

ANNETT, M. (2002). *Handedness and brain asymmetry: The right shift theory*. Hove: Psychology Press.

BRADSHAW-McANULTY, G., HICKS, R. E., & KINSBOURNE, M. (1984). Pathological left-handedness and familial sinistrality in relation to degree of mental retardation. *Brain and Cognition*, 3(4), pp. 349–356.

BRUML, H. (1972). Age changes in preference and skill measures of handedness. *Perceptual and Motor Skills*, 34(1), pp. 3–14.

COREN, S. (1995). Age and handedness: Patterns of change in the population and sex differences become visible with increased statistical power. *Canadian Journal of Experimental Psychology*, 49(3), pp. 376–386.

DRAGOVIC, M. (2004). Categorization and validation of handedness using latent class analysis. *Acta Neuropsychiatrica*, 16(4), pp. 212–218.

DRAGOVIC, M. & HAMMOND, G. (2005). Handedness in schizophrenia: A quantitative review of evidence. *Acta Psychiatrica Scandinavica*, 111(6), pp. 410–419.

DRAGOVIC, M. & HAMMOND, G. (2007). A classification of handedness using the Annett Hand Preference Questionnaire. *British Journal of Psychology*, 98(Pt 3), pp. 375–387.

DRAGOVIC, M., MILENKOVIC, S., & HAMMOND, G. (2008). The distribution of hand preference is discrete: A taxometric examination. *British Journal of Psychology*, 99(Pt 4), pp. 445–459.

FLEMINGER, J. J., DALTON, R., & STANDAGE, K. J. (1977). Age as a factor in the handedness of adults. *Neuropsychologia*, 15(3), pp. 471–473.

GALOBARDES, B., BERNSTEIN, M. S., & MORABIA, A. (1999). The association between switching hand preference and the declining prevalence of left-handedness with age. *American Journal of Public Health*, 89(12), pp. 1873–1875.

HUGDAHL, K., ZAUCHA, K., SATZ, P., MITRUSHINA, M., & MILLER, E. N. (1996). Left-handedness and age: Comparing writing/ drawing and other manual activities. *Laterality*, 1(3), pp. 177–183.

MANDAL, M. K., PANDEY, G., DAS, C. T., & BRYDEN, M. P. (1998). Handedness in mental retardation. *Laterality*, 3(3), pp. 221–225.

McMANUS, I. C. (1985a). Handedness, language dominance and aphasia: A genetic model. *Psychological Medicine Monograph Supplement*, 8, pp. 1–40.

McMANUS, I. C. (1985b). Right- and left-hand skill: Failure of the right shift model. *British Journal of Psychology*, 76 (Pt 1), pp. 1–34.

McMANUS, I. C. (1991). The inheritance of left-handedness. In: G. R. Bock & J. Marsh (eds), *Biological Asymmetry and Handedness* (pp. 251–281). Chichester, UK: Wiley.

McMANUS, I. C. (2007). *The inheritance of left-handedness Ciba Foundation Symposium 162 – Biological Asymmetry and Handedness* (pp. 251–281). John Wiley & Sons, Ltd.

McMANUS, I. C., SIK, G., COLE, D. R., MELLON, A. F., WONG, J., & KLOSS, J. (1988). The development of handedness in children. *British Journal of Developmental Psychology*, 6, pp. 257–273.

MEDLAND, S. E., PERELLE, I., DE MONTE, V., & EHRMAN, L. (2004). Effects of culture, sex, and age on the distribution of handedness: An evaluation of the sensitivity of three measures of handedness. *Laterality*, 9(3), pp. 287–297.

OLDFIELD, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, 9(1), pp. 97–113.

R Development Core Team. (2012). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

RAYMOND, M., & PONTIER, D. (2004). Is there geographical variation in human handedness? *Laterality*, 9(1), 35–51.
RODRIGUEZ, A., KAAKINEN, M., MOILANEN, I., TAANILA, A., McGOUGH, J. J., LOO, S. et al. (2010). Mixed-handedness is linked to mental health problems in children and adolescents. *Pediatrics*, 125(2), pp. e340–348.
SOPER, H. V., SATZ, P., ORSINI, D. L., HENRY, R. R., ZVI, J. C., & SCHULMAN, M. (1986). Handedness patterns in autism suggest subtypes. *Journal of Autism and Developmental Disorders*, 16(2), 155–167.
ŠTOCHL, J. (2012). *Five essays on laterality*. Saarbrücken: Lambert Academic Publishing.
ŠTOCHL, J., CROUDACE, T., BROŽOVÁ, H., KLEMPÍŘ, J., ROTH, J., & RŮŽIČKA, E. (2012). Changes of hand preference in Parkinson's disease. *Journal of Neural Transmission*, 119(6), pp. 693–696.
ŠTOCHL, J., HAGTVET, K. A., BROŽOVÁ, H., KLEMPÍŘ, J., ROTH, J., & RŮŽIČKA, E. (2009). Handedness does not predict side of onset of motor symptoms in Parkinson's disease. *Movement Disorders*, 24(12), pp. 1836–1839.
TAPLEY, S. M. & BRYDEN, M. P. (1985). A group test for the assessment of performance between the hands. *Neuropsychologia*, 23, pp. 215–221.
VAN DER HOORN, A., BARTELS, A. L., LEENDERS, K. L., & DE JONG, B. M. (2011). Handedness and dominant side of symptoms in Parkinson's disease. *Parkinsonism & Related Disorders*, 17(1), pp. 58–60.
VAN DER HOORN, A., OLDEHINKEL, A. J., ORMEL, J., BRUGGEMAN, R., UITERWAAL, C. S., & BURGER, H. (2010). Non-right-handedness and mental health problems among adolescents from the general population: The trails study. *Laterality*, 15(3), pp. 304–316.
YUST-KATZ, S., TESLER, D., TREVES, T., MELAMED, E., & DJALDETTI, R. (2008). Handedness as a predictor of side of onset of Parkinson's disease. *Parkinsonism & Related Disorders*, 14(8), pp. 633–635.

ANALÝZA LATENTNÍCH TŘÍD DOTAZNÍKŮ LATERALITY

JAN ŠTOCHL, TIM CROUDACE

SOUHRN

Mezi odbornou veřejností se v posledních několika letech živě debatuje, zda-li je rukovost (handedness) svou povahou spíše intervalová či kategorická, a pokud kategorická, kolik skupin z hlediska rukovosti je vhodné rozlišovat. Tento článek řeší tuto problematiku ze statistického pohledu. Analýza latentních tříd je použita jako prostředek k testování počtu homogeních skupin z hlediska rukovosti. V empirické části jsou analyzovány a srovnávány datové soubory zdravé populace (n = 1526) a populace parkinsoniků (n = 476). Výsledky ukazují, že z hlediska rukovosti je u obou populací nejvhodnější rozlišovat 3 skupiny; nicméně interpretace těchto skupin je u populace parkinsoniků odlišná.

Klíčová slova: analýza latentních tříd, lateralita, Parkinsonova nemoc

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