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Monitoring the social gradient: Inequalities in use of blood pressure monitors in the HUNT study☆

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A B S T R A C T

Aim: To investigate the cross-sectional and longitudinal social gradient in use of blood pressure monitors, an innovative health technology.

Background: This is one of the first studies of social inequalities in the utilization of an end-user health technology in a universal health care context. The diffusion of innovation (DoI) and fundamental cause (FCT) theories predicts a widening of inequalities with the introduction of a new technology.

Data and methods: Two waves (N > 18,000) of the Nord-Trøndelag Health Study (HUNT), conducted in 1997 and 2008. Dependent variables were three self-reported indicators of blood pressure monitor use. Independent variables were educational attainment and income quartiles. Control variables were gender, age, and blood pressure.

Results: For the blood pressure monitor variable from 1997, there was evidence of an educational gradient. No social inequalities were found for the 2008 monitor variable. When interacting socio-economic status with a survey wave dummy, results showed a social gradient from 1997 becoming smaller or non-significant in 2008. These results are supportive of the DoI and FCT, suggesting that the use of technology may initially generate health inequalities, which decrease as the technology is diffused across all social strata.

1. Introduction

Technological innovation within the health and medical field has been extensive over the last decades and has been proposed as a remedy to many of the central challenges facing modern health care, related to public health as well as biomedical or economic issues [1]. Research have also demonstrated a positive association between technological development and health outcomes, such as Dutta, Gupta, and Sengupta's [2] study of information communications technology and infant mortality in selected Asian countries.

However, several pitfalls have been suggested, for instance the technologies' "impact upon healthcare costs, the creation of difficult ethical dilemmas, issues of personal privacy, and threats to the professional relationships between patients, families, and physicians" [3]. Inequalities in outcome are also recognized as consequences of the diffusion of innovations [4]. In much of the health inequalities literature, the diffusion of medical innovations has proved to have an initial inequality-generating function; when new technologies or information is introduced, it tends to be disproportionally utilized by the higher social strata (cf [5–8]). This is in line with a seminal theory in the field, the fundamental cause theory (FCT), which proposes that time- and context-dependent mechanisms will connect social positions with health outcomes [9]. In countries with high living standards and advanced welfare and health care systems, the introduction of medical innovations may be a particularly relevant mechanism generating health inequalities [6,10].

This article examines how individual use of blood pressure monitoring technology is distributed across socio-economic positions. This is done by using two survey waves of the Norwegian Nord-Trøndelag Health Study (HUNT) from 1997 to 2008, which include questions on experiences with blood pressure self-monitoring technologies, which is further linked with register data on income and education. Details on the HUNT dataset is provided in section 3 (Data and methods). To my knowledge, this is the first investigation of social inequalities in use of an innovative, end-user health technology in a universal health care context.

2. Background

Throughout the 20th century, growing real income was paired with increased life expectancy in most high-income countries; among the proposed explanations were better nutrition, public health improvements, vaccination, and innovations in medical treatments [11]. Nevertheless, one's position in the social structure, however measured,

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has been and continues to be a significant predictor of health outcomes, resulting in social inequalities in health [12,13]. Attempts to explain this so-called paradox, where inequalities have persisted or increased in the face of medical development and welfare state expansion, have been made by both general social theories and theories with attention to the distribution of specific health-relevant resources [10].

The fundamental cause theory (FCT) have gained foothold in recent years. It was formulated by Link and Phelan [9] as a reaction to what they saw as a prevailing approach in health inequality research: to mainly investigate the social distribution of risk factors located proximate to the health outcome in the causal chain. Link and Phelan [9, p. 85] argued for the importance of looking upstream at "the more fundamental factors that put people at risk of risks". Within this line of reasoning, social conditions are the fundamental causes of health inequality; if the unequal distribution of vital, flexible resources persist, so will inequalities in health outcomes. These resources are associated with, but not reduced to, indicators of socio-economic status, and often mentioned in this literature are the resources of money, knowledge, power, prestige, and social connections. They are flexible in their nature, meaning that they may be employed to gain health benefits over time and across several contexts [9]. Housing conditions may be a less relevant mechanism for health inequalities in industrialized countries in 2019 than in 1850; but if resources are still unevenly distributed, this mechanism will be replaced by another, e.g. the utilization of medical technology, and health inequalities will endure.

2.1. *Technology and health inequalities*

The diffusion and utilization of innovative health technologies represent a good case for testing the FCT: they are likely to improve population health; one can determine a point in time where these innovations did not exist, i.e. where they did not mediate social inequalities in health; and they are human inventions rather than acts of nature, thus illustrating the social shaping of health [6]; pp. 378–379). Investigating innovations' effect on health inequalities resonates well with studies of the diffusion of innovations (DoI). This theory proposes that innovations are successively adopted across population groups, which are labelled innovators, early adopters, early majority, late majority, and laggards. These adopter groups are associated with socio-economic status (SES) groups, it is therefore assumed that innovations follow a social-hierarchical adoption pattern, where people of high SES are the first to use and benefit from new knowledge and technology [4,14]. Cutler, Deaton, and Lleras-Muney [11] have written of how the emergence of a health gradient has followed transitions in knowledge, science, and technology, examples include Enlightenment ideas, the germ theory of disease, and knowledge of the health consequences of smoking. The following section reviews selected research on social inequalities within use of and access to innovative medical technology; many of them with an FCT or DoI perspective. The literature review is structured by Weiss and colleagues' [15] categories of innovative health technologies.

Some studies have focused on what Weiss et al. [15] termed *indirect-use gatekeeper technologies*, where end-users of the technology are dependent on gatekeepers (usually medical professionals) for access and utilization. Relevant examples are screenings and surgery procedures. Link et al. [6] focused on the social gradient in the use of two medical innovations: pap smears and mammography. Both innovations showed social inequalities over the study years (1988–1995). The use of pap smears was stable, while the use of mammography showed a rapid increase, meaning that all groups benefited from the innovation, but the top socio-economic groups benefited more [6]. Gadeyne et al. [5] found that breast cancer mortality went a positive to a negative association with education from the 1990s to the 2000s; authors interpret that this is in line with the FCT - increased information and availability of mammography screening have contributed to the inversion of the gradient. Explicitly testing the FCT and its link with the DoI, Zapata-Moya, Willems, and Bracke [16] found that the influence of SES on preventive practices varied with the practices' diffusion stages; prostate specific antigen tests in an early majority stage showed the largest inequalities, blood pressure checks in a late majority/laggard stage showed the smallest. Willems and Bracke [17,18] found substantial educational inequalities in cancer screening across European countries, with organized screening programs and physician initiatives partially levelling these disparities. In a longitudinal analysis of cancer screening across Belgian regions, Willems and Bracke [19] found greater fluctuation for screening of breast cancer than for cervical cancer, with a reduction of inequalities in a region where official screening programs were initiated. Korda, Clements, and Dixon [20] and Korda, Clements, and Kelman [21] investigated social inequalities in coronary surgery, a technology with strong features of gatekeeping. Authors found socio-economic gradients for several procedures, including a diffusion lag, meaning that people of high SES had an earlier peak in the uptake of coronary surgery.

Another strand of research has concentrated on *direct-use gatekeeper technologies*, where the people affected by the innovation are responsible for using it, but still depend on gatekeepers for access [15]. Many of these studies have utilized longitudinal data on different types of prescription drugs. Goldman and Lakdawalla [22] found that the introduction of simplifying hypertension drugs contributed to a contraction of health inequalities, while a new, somewhat complicated HIV treatment regimen (HAART) was disproportionally utilized by the better educated. This was supported by findings from Rubin, Colen, and Link's Rubin, Colen, and Link's [23] analysis of inequalities in HIV/AIDS mortality, which appeared to increase after the introduction of HAART. Similar conclusions were drawn by Chang and Lauderdale [24]; who found that the introduction and diffusion of the statin drug over the years 1976–2004 correlated with a widening of disparities in cholesterol. Finally, Glied and Lleras-Muney [25] used state mortality changes and approved drug ingredients as general and specific measures of health-related progress and innovation, and found steeper educational gradients for diseases where innovation rates were high.

Direct end-user technologies are "technologies accessed and used directly by the end user"; these technologies depend to a larger degree on individual user agency [15]. Digital health literacy or so-called eHealth devices were the study objects in several of the studies included in Weiss and colleagues' [15] review. Two studies using Australian focus groups showed that a number of determinants hindered disadvantaged groups in utilizing digital technology to gain health benefits, including financial strains, lacking English or technological literacy, unstable housing and employment situations, poor health, and lacking social networks [26,27]. Socio-economic inequalities were also demonstrated in Perez and colleagues' [28] investigation of digital health information processing strategies, where low-SES participants showed a tendency for intuitive – "unconscious, rapid, automatic, and high capacity thin" – strategies. Individual level utilization of direct end-user technology can also be affected by structural factors such as cell phone disconnection, as shown in Gonzales, Ems, and Suri's [29] results from interviews at two free health clinics in the US.

Finally, health-beneficial information may also follow the same hierarchical pattern of diffusion. A well-known example is the development of the quitting 'epidemic' in smoking across Europe: As the negative effects of tobacco smoking became known, people of higher social positions were the first to adjust their behavior, with an inversion and a widening of smoking-related health inequalities to follow [10]. Using cross-sectional survey data on US teenagers and the HPV vaccine, Polonijo and Carpiano [7] found that there was a significant social gradient with regards to knowledge, recommendation by physician, and finally uptake of the vaccine. These inequalities were significant when using mother's education and household income as SES measures, as well as for race/ethnicity, leading the authors to conclude that disparities were present in all stages of innovation diffusion, from first knowledge to actual uptake [7]. Looking at health outcomes resulting from information disparities, Wang and colleagues [8] found that an interaction between SES and a measure of informational diffusion was significantly associated with colorectal cancer mortality, indicating that high information diffusion rates may reduce the impact of SES on mortality.

For all categories of technologies and measures of SES, social inequalities in access, use, and health outcomes have been demonstrated; people with more resources tend to benefit more from medical innovation. The reviewed literature thus suggests support to the FCT notion that health-related outcomes, in this context use of medical technologies, are fundamentally influenced by social conditions. Although the patterns are similar, the mechanisms connecting SES to technology use, access, and effect may differ. High-SES people may need to deploy other resources to access a technology where a gatekeeper is involved compared to the direct end-user technologies. For instance, material resources like money may be beneficial in settings where a medical innovation is less regulated and more dependent on out-of-pocket payments, particularly if that innovation has not yet been mass produced and widely distributed, and therefore is expensive to obtain. Likewise, immaterial resources like knowledge and social connections may be of more relevance in settings where technology use and access are governed by health professionals.

2.2. Study context

In this study, blood pressure monitors serve as a case for investigating technology's role in generating and/or mediating health inequalities. The traditional mercury sphygmomanometer has over the last decades been phased out as the standard blood pressure measuring equipment, and new types of measurement tools have become available to both health professionals and patients, such as aneroid and oscillometric technology [30]. In a survey conducted among 173 general practitioners (GPs) in 45 medical centers in central Norway, only 7% of the GPs reported not having monitors available for patients to loan 24-h automatic blood pressure monitors [30]. Blood pressure monitors have also become increasingly available for personal purchase in stores. Prevalence figures from the HUNT study (Table 1) suggest an increase in self-reported use of blood pressure monitors among respondents with indications of hypertension. On a variable included in the second HUNT wave (HUNT2, 1997), 4.7% of respondents report having a blood pressure monitor at home; this is similar to the direct end-user technologies, with the individual patients administrating the monitor. On a variable included in the third HUNT wave (HUNT3, 2008), 27.4% reports having used a 24-h blood pressure monitor; this measure resembles a direct-use gatekeeper technology, where the monitor would be provided by the GP and loaned out to the patient. On a variable included in both HUNT2 and HUNT3, a total of 14.6% of respondents report having measured blood pressure at home; stratifying the two surveys return a 9.8% prevalence in HUNT2 and a 17.6% prevalence in HUNT3. Although not completely comparable, these figures combined indicate an increased adoption of personal blood pressure monitoring equipment from the years 1997–2008. All in all, this can be interpreted as an indication of blood pressure monitors being widely diffused in early 21st century Norway, reaching a diffusion stage where the majority of the population can access and use the innovation. As the Norwegian health care system in characterized by a high degree of universality, measures for treatment and prevention should be equally distributed across the social strata. Nevertheless, research on different medical services in Norway have proved substantial social inequalities in access and utilization [31–35].

Through what can be characterized as rapid medical and technological development, where the ability of both health services and individuals to prevent, detect, and treat disease has increased, Norway have seen a drop in cardiovascular disease (CVD) and related mortality. However, the social inequalities for this cause of death persist [11,36]. High blood pressure is an important risk factor and determinant of inequalities in this aspect. While absolute prevalence has decreased, and the overall use of remedies like blood pressure medication and measuring devices increased, inequalities in hypertension have persisted [37,38].

The reviewed research has indicated that while introducing innovative technology or new information to the health field may have beneficial effects on average, they may also generate and widen social inequalities in health. Social inequalities in health have continued to persist in the Nordic welfare states, despite their universalistic principles and advanced health care systems [13]. Could inequality structures in technology use contribute to explain these trends?

The FCT explains persisting health inequalities with the continuous emergence of mechanisms connecting SES and disease. Clouston and colleagues [39] have described a shortcoming of the FCT: it does not explain how the same resources and health outcomes show different associations across different contexts. Stages in the diffusion process could represent these contexts and contribute to explain how resources may have varying effects. The link between SES and a disease may be stronger in a context where a technology or knowledge is in an early diffusion stage, where only the earlier adopters can reap the health benefits, compared to a later stage where adoption is more widespread and individual available resources are of less relevance. Zapata-Moya and colleagues [59, p. 189] highlight how "the conjunction with DoI theory adds a contextual and temporal dimension to FCT", and this study is an attempt to further follow up this joining of theories with empirical research covering several time points.

Table 1
Descriptive statistics – distribution and mean.

Variable	HUNT2+3	HUNT2	HUNT3
	Distribution/Mean (SD, Min-Max)	Distribution/Mean (SD, Min-Max)	Distribution/Mean (SD, Min-Max)
Primary education	37.8%	49.7%	30.2%
Secondary education	48.8%	41.8%	53.4%
Tertiary education	13.3%	8.5%	16.5%
Income quartile group 1	54.9%	62.2%	50.1%
Income quartile group 2	8.5%	9.7%	7.7%
Income quartile group 3	21.3%	15.4%	25.1%
Income quartile group 4	15.4%	12.7%	17.2%
Age	65.3 (12.2, 19.5–99.3)	65.4 (12.0, 20.8–99.3)	65.2 (12.3, 19.5–96.9)
Systolic BP	145.4 (22.7, 67–260)	157.0 (22.7, 81–239)	138.3 (19.5, 67–260)
Diastolic BP	80.5 (13.6, 36–156)	88.6 (12.8, 44–156)	75.6 (11.5, 36–137)
Gender (Man)	46.4%	43.3%	48.5%
Self-measure	14.6%		
Home-measure		4.7%	
Auto-measure			27.4%
N	18,153 (15,705)[a]	6910	11,133

[a] Observations (individual respondents).

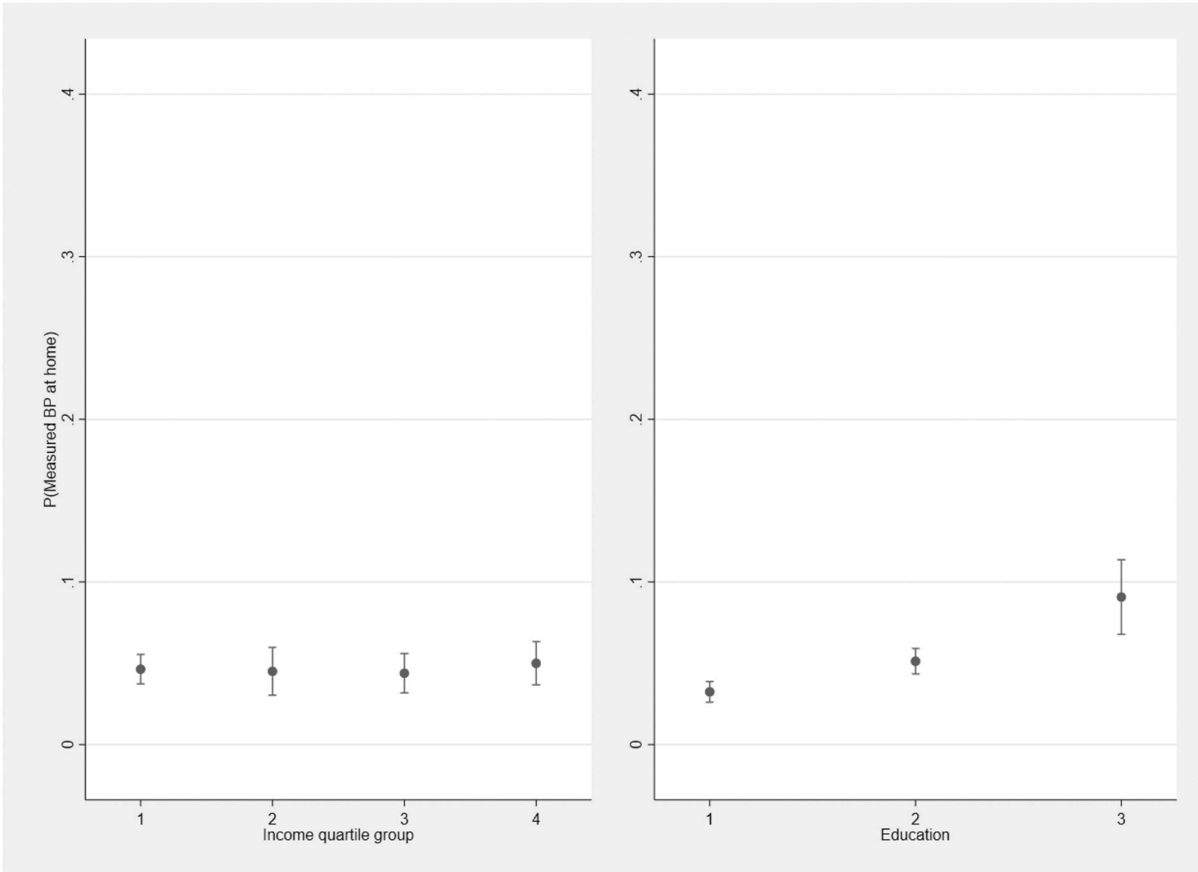

Fig. 1. Predicted probabilities of Home-measure (HUNT2).

3. Data and methods

The Nord-Trøndelag Health Study (HUNT) is a population-based panel study carried out in 1984–86 (HUNT1), 1995–97 (HUNT2), and 2006–08 (HUNT3) in Nord-Trøndelag County in Norway. The two latter waves will be utilized in this study. This county is to a large degree representative of the Norwegian population regarding demography, economy, morbidity, and mortality, and with approximately 120,000 respondents in total and 28,000 respondents participating in all three waves, the HUNT study provides representative, reliable, and valid measurements of the Norwegian population's health during the last decades [40,41]. All respondents above the age of 20 in Nord-Trøndelag county were invited, response rates were 69% and 54% for HUNT2 and HUNT3 respectively. The questions on blood pressure monitors were included in a cardiovascular questionnaire module given to respondents who either reported use of hypertension medication (HUNT2) or showed indications of cardiovascular or renal disease in the baseline screening (HUNT3). The research project was given approval by the Regional Committee for Medical and Health Research Ethics in Central Norway (REK-Mid).

3.1. Variables

The analyses utilized three dependent variables indicating use of blood pressure measurement equipment, all dichotomous with "Yes" and "No" as question choices. A question included in both HUNT2 and HUNT3 was worded "Have you ever measured your blood pressure yourself at home?" (*Self-measure* in tables). Further, analyses were performed on dependent variables worded "Do you have a blood pressure monitor at home?" (HUNT2, *Home-measure* in tables) and "Have you used a 24-h blood pressure monitor?" (HUNT3, *Auto-measure* in tables).

Two explanatory variables measuring SES were included: education measured as completed primary, secondary or tertiary education (following the ISCED classification) and yearly individual income divided into quartiles. These variables are register data collected by Statistics Norway and linked to HUNT respondents through their personal identification number. The two SES variables measures are meant to capture the health-relevant resources associated with social position and are added to the models both separately and combined. Systolic and diastolic blood pressure (SBP and DBP), clinically measured by health professionals, were included as independent control variables, since patients with high measured blood pressure often are advised by their GP to also have their blood pressure measured out of office [42,43].

Age is thought to be associated with both respondents' overall health and their willingness to utilize innovative technologies. This variable was measured in years and also included as a squared term to control for potential curve-linearity. Gender was also included as a control, as men and women may have different needs for self-monitoring their blood pressure, e.g. related to reducing the risk of preeclampsia during pregnancy (cf. [44]). Previous research has also demonstrated gender inequalities in blood pressure. Gender was treated as a binary variable with women as the reference. A survey wave dummy was added to the model in order to control for time-variant, unmeasured variables which may impact the respondents in each study wave. This dummy was used to construct two multiplicative interaction terms between survey wave and 1) income quartile and 2) educational attainment in order to investigate whether SES had a different impact on technology use at the two time points. Table 1 displays descriptive statistics for dependent and independent variables.

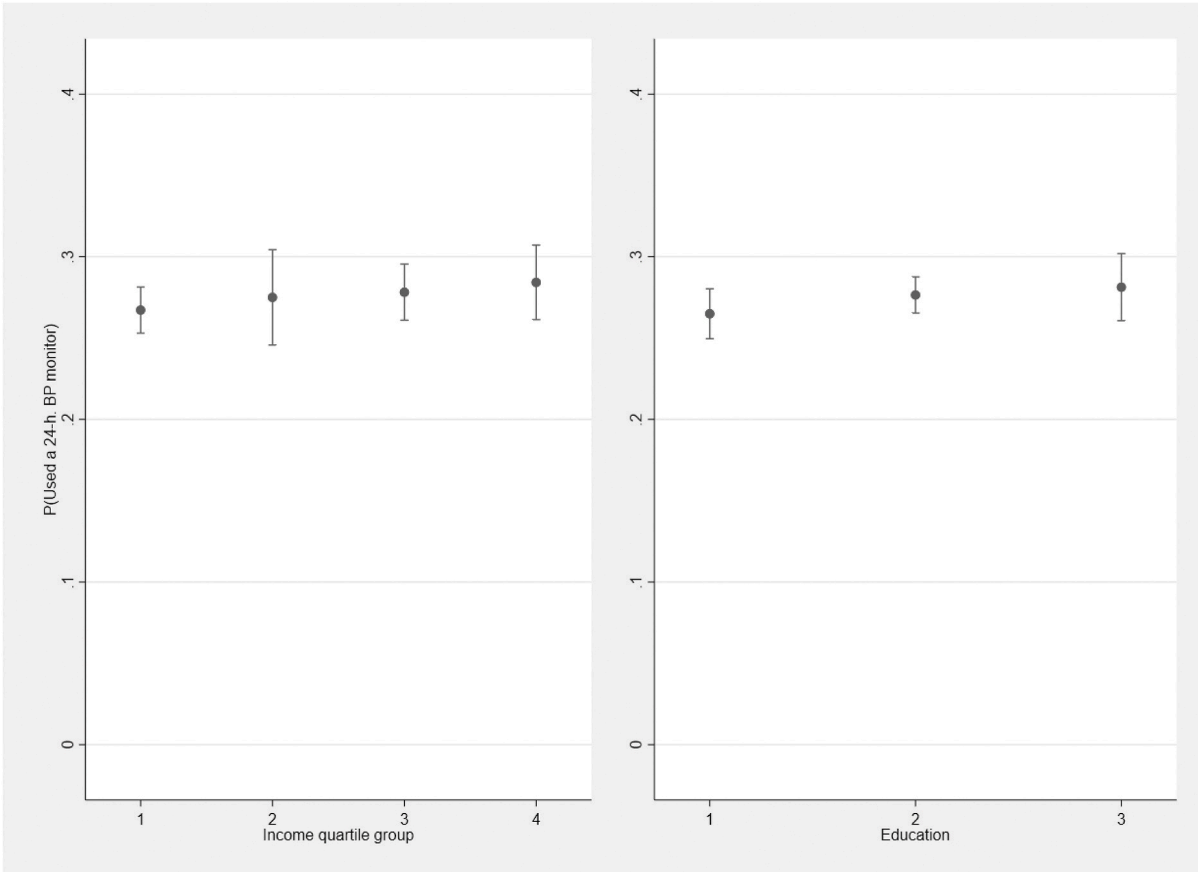

Fig. 2. Predicted probabilities of Auto-measure (HUNT3).

3.2. Methods

Since the dependent variable only allowed data collection from one or two time points, panel data methods such as fixed effects regression were unsuitable. In the analyses using the question included in both HUNT2 and HUNT3, data from the two waves were pooled, and logistic regression were performed with robust standard errors adjusting for clustering at the individual respondent. For the two other dependent variables, cross-sectional logistic regression analyses were performed. Models were first run with income and education entered separately, then together in the same model. Lastly, in the analyses using data from both HUNT2 and HUNT3, models including interactions between the survey wave dummy and the SES variables were run. Marginal predicted probabilities were calculated and are displayed graphically in Figs. 1–3. Table 2 displays the final regression models for all three dependent variables. In an online appendix are the partial regression modelling for all dependent tables displayed in tables A.1-A.3. Analyses were performed using software Stata 15.

4. Results

First looking at the control variables, we find that age had significantly positive associations with having a 24-h blood pressure monitor in HUNT3 and having ever measured blood pressure at home in HUNT2 and HUNT3. A weak, but significant negative estimate for the squared variable indicates a diminishing effect of age on the probability of utilizing blood pressure monitoring equipment. Systolic and diastolic blood pressure showed mostly positive, significant associations with equipment use; an exception being diastolic blood pressure in HUNT2, which were not statistically significant. Being male was positively associated with having a blood pressure monitor at home in 1997 (HUNT2), negatively associated with using a 24-h blood pressure monitor in 2008 (HUNT3) and showed no significant association with ever having measured blood pressure at home (HUNT2 and HUNT3). Finally, the survey dummy estimate was positive in the models including both HUNT waves, meaning that the probability of measuring one's blood pressure at home increased from 1997 to 2008.

Moving on to the explanatory SES variables, the analyses showed that in HUNT2, income quartile groups was not significantly associated with having a blood pressure monitor at home. Educational attainment however, showed a positive, significant association with the *Home-measure* variable. Having secondary or tertiary compared to primary education was associated with respectively 2 and 6% points higher probability of having a blood pressure monitor at home, indicating a full educational gradient. These educational effects were present also when the income variable was included. In the models with the 24-h blood pressure monitor as a dependent variable (HUNT3), neither income quartile group nor educational attainment showed significant associations.

Lastly, the probability of ever having measured one's blood pressure at home increased by approximately 2% points from the first to the second and third income quartile group, and by additionally 2% points to the fourth group (P = 17.4% vs. P = 15.2% vs. P = 14.9% vs. P = 13.0%). Educational attainment was also significantly associated with this dependent variable, with approximately 2.7 and 7.5% points higher probability for the secondary and tertiary educated compared to the primary educated (12.0% vs. 14.7% vs. 19.5%). In these models, the interaction terms showed that the effect of both income and education significantly decreased from 1997 to 2008. Fig. 1 illustrate how the social gradient in 1997 for using both income and education is reduced in 2008. For the lowest income quartile group, the probability of ever having measured one's blood pressure at home increased from 6.4%

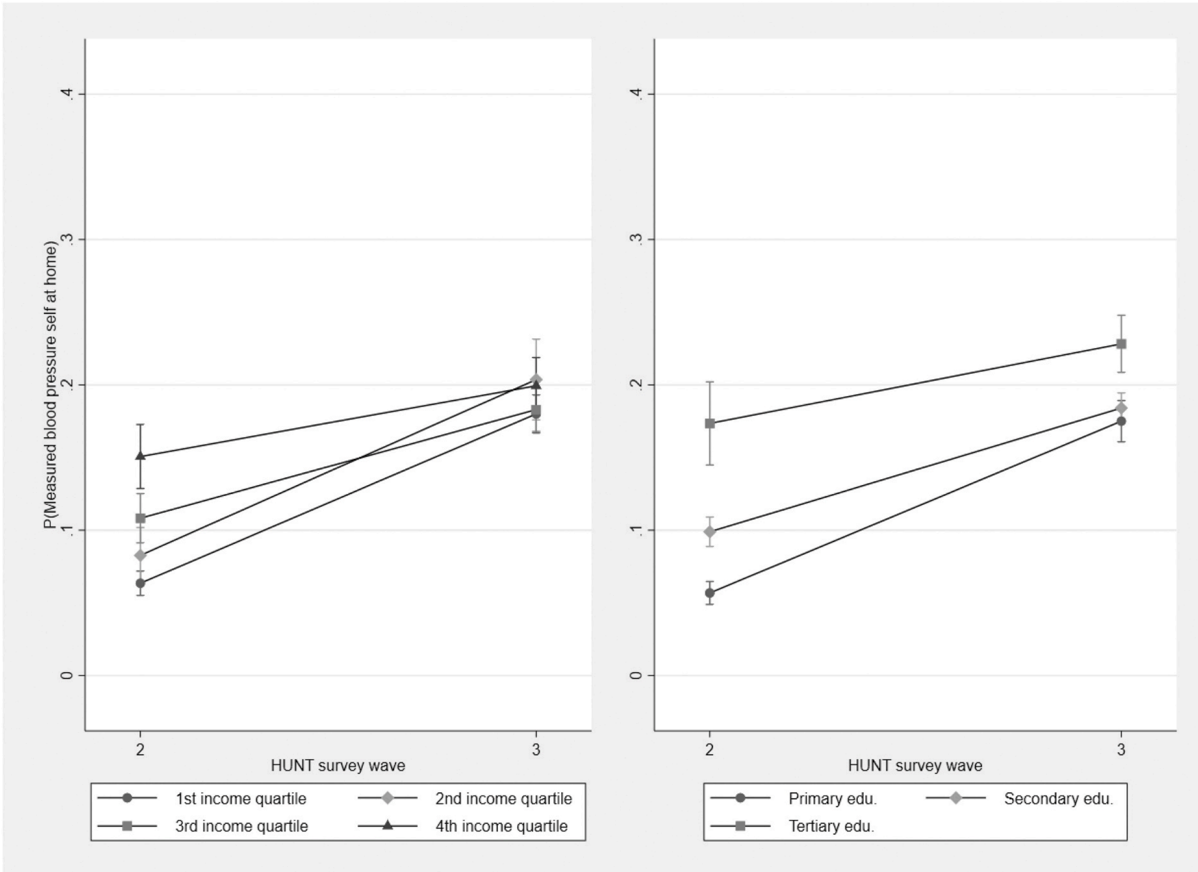

Fig. 3. Predicted probabilities of Self-measure (HUNT2+3).

(95% CI: 5.5–7.2) to 18.0% (95% CI: 16.7–19.3), while for the highest income quartile group, this probability increased from 15.1% (95% CI: 12.9–17.3) to 19.9% (95% CI: 18.0–21.9). In 1997, there were substantial differences between income quartile groups, with the fourth group having significantly higher probabilities than all other groups of ever having measured blood pressure at home; in 2008, differences between income quartile groups were non-significant. The pattern was similar for educational attainment; from 5.7% to 17.5% for the primary educated, from 9.9% to 18.4% the secondary educated, and from 17.3% to 22.8% for the tertiary educated. A tripart educational gradient in 1997 became a two-part gap in 2008, with the difference between the primary and secondary educated category being non-significant in 2008. In sensitivity analyses, income and education were added separately to the model, with similar results.

Using the pseudo-R^2 estimates to assess the models, the education variable appeared to improve model fit the more than the income quartile group variable, but differences were small; the pseudo-R^2 estimates vary between 3.7% and 5.9%.

5. Discussion

Results from analyses of three variables measuring of personal blood pressure monitor use suggested that a social gradient was more present at earlier time points, both when comparing estimates across survey waves, and when including an interaction term with a survey wave dummy. Educational attainment showed overall stronger and more robust associations with technology use than personal income.

The DoI theory predicts that innovations are diffused in an S-shaped pattern, first reaching groups of early adopters with characteristics such as higher educational attainment, greater wealth, and higher placement on other measures of social status [4]. The cross-sectional and longitudinal analyses of this article indicate support for these predictions; the effect of income and education on blood pressure monitor use diminish at later time points, possibly due to the innovation being at a later stage in the diffusion process and therefore utilized across all social strata. Results can also be interpreted as support for the FCT; at the early adoption stages of a health technology, the resources available to the rich and higher educated enable them to adopt such innovations before the poorer and less educated, with widening health inequalities a plausible consequence.

Returning to the typology of innovative health technologies, blood pressure monitors can be classified as both a direct-use gatekeeper technology, where use follows from a GP-patient consultation, and a direct end-user technology, as it increasingly has become available at the private market for individuals to buy and use at their own initiative. As noted above, the two different measures of experiences with blood pressure monitors in HUNT2 and HUNT3 can be seen as representing respectively direct end-user technology and gatekeeper technology. On the one hand, the steeper social gradient in use of the former technology can be interpreted longitudinally, as a result of blood pressure monitors in general moving across diffusion stages, with different inequality rates as a consequence. On the other hand, it can be interpreted cross-sectionally, as a result of the two technologies' different inherent characteristics, where more gatekeeping of health-beneficial technologies results in less inequalities. The latter interpretation is also in line with the policy implications derived from the FCT; health inequalities can be avoided if interventions are designed to not require individual deployment of flexible resources [45].

Proceeding to the mechanisms connecting SES to blood pressure monitor use: If access to the technology is dependent on a health professional gatekeeper, inequalities in use may reflect that GPs, with or without intent, prioritize rich and well-educated patients in a

Table 2
Final regression models, all dependent variables.

	Model 1 Home-measure (HUNT2)	Model 2 Auto-measure (HUNT3)	Model 3 Self-measure (HUNT2+3)	Model 4 Self-measure (HUNT2+3)	Model 5 Self-measure (HUNT2+3)
Age	1.084 [0.999,1.177]	1.175*** [1.139,1.213]	1.064*** [1.035,1.093]	1.066*** [1.038,1.096]	1.068*** [1.039,1.097]
Age (squared)	0.999* [0.998,1.000]	0.999*** [0.998,0.999]	0.999*** [0.999,1.000]	0.999*** [0.999,1.000]	0.999*** [0.999,1.000]
Systolic blood pressure	1.008* [1.001,1.016]	1.011*** [1.008,1.014]	1.009*** [1.006,1.012]	1.009*** [1.006,1.012]	1.010*** [1.007,1.012]
Diastolic blood pressure	1.012 [0.999,1.024]	1.013*** [1.008,1.018]	1.008** [1.003,1.013]	1.008*** [1.004,1.013]	1.008*** [1.003,1.013]
Gender (man)	1.853*** [1.447,2.373]	0.773*** [0.705,0.847]	1.035 [0.941,1.139]	1.023 [0.929,1.126]	1.018 [0.925,1.120]
Income quartile group 2	0.969 [0.640,1.468]	1.042 [0.881,1.233]	1.203* [1.020,1.420]	1.195* [1.013,1.411]	1.335 [0.998,1.786]
Income quartile group 3	0.942 [0.632,1.405]	1.060 [0.932,1.205]	1.182* [1.031,1.355]	1.171* [1.022,1.342]	1.807*** [1.433,2.278]
Income quartile group 4	1.085 [0.719,1.638]	1.093 [0.934,1.279]	1.430*** [1.220,1.676]	1.418*** [1.211,1.662]	2.664*** [2.098,3.383]
Secondary education	1.622*** [1.242,2.119]	1.063 [0.961,1.176]	1.277*** [1.145,1.425]	1.840*** [1.530,2.213]	1.247*** [1.118,1.391]
Tertiary education	3.034*** [2.115,4.354]	1.090 [0.950,1.251]	1.816*** [1.572,2.097]	3.575*** [2.773,4.610]	1.798*** [1.559,2.074]
HUNT wave 3			2.330*** [2.097,2.589]	3.615*** [3.036,4.305]	3.316*** [2.841,3.871]
Income quartile 2 * HUNT wave 3				0.877 [0.625,1.230]	
Income quartile 3 * HUNT wave 3				0.565*** [0.444,0.719]	
Income quartile 4 * HUNT wave 3				0.428*** [0.337,0.542]	
Secondary edu. * HUNT wave 3					0.579*** [0.471,0.711]
Tertiary edu. * HUNT wave 3					0.395*** [0.300,0.519]
Pseudo-R^2	0.0577	0.0376	0.0553	0.0583	0.0589
N	6910	11,133	18,153	18,153	18,153

Odds ratios; 95% confidence intervals in brackets.
*p < 0.05, **p < 0.01, ***p < 0.001.

technology's early phase. It could also indicate that rich and well-educated patients possess resources, such as networks, knowledge or communication skills, that could influence, convince or pressure physicians to include innovative technologies in their treatment. Unequal access to medical innovations has been demonstrated in health care systems with strong private features, such as in the US (cf. [6,7]), but also in more universal health care systems like the Australian, where the presence of private health insurance may explain some of the social gradient [20,21]. In the Norwegian health care system, research has demonstrated inequalities in access to specialist treatment and in the extent of primary care (cf. [31–35]), where mechanisms could be similar to the unequal use of and access to mecical technologies.

On the other hand, if blood pressure monitors are viewed as direct end-user technologies, other mechanisms may be relevant. Since this class of technology is more sensitive to individual agency, income and education may be directly associated with individual and structural adoption barriers such as pricing and lacking knowledge. Furthermore, previous research has shown that low SES can be associated with more intuitive strategies when navigating the health technology field [29]. With regards to blood pressure monitors, *why* and *how to* use such equipment at home may be questions without intuitive answers. Though blood pressure is an important risk factor for cardiovascular mortality, it may be more related to the concept of *disease* than to *illness* or *sickness*, i.e. the condition may be discovered by medical professionals before it is experienced as a lack of well-being by a patient (illness) or recognized as hampering one's function in society (sickness) [46]. With this in mind, there may also be differences in individual motivations for choosing to use innovative health technologies. For a poor and low educated person's present and prospective life situation, the relative improvement of using the latest blood pressure monitoring technology may be less than obvious [47]; have called such behavior an 'appropriate response' to limitations in one's life chances.

The statistical models in this article included two measures of social stratification: income quartile group and educational attainment. These are commonly used indicators when investigating socio-economic inequality – but may be connected to health-related outcomes through very different pathways [48]. Income may be a more direct measure of material resources but is sensitive to changes over the life course, while education is a more stable measure of social stratification, changing little over most parts of a respondents' life, and a substantial predictor of social status [49,50]. In analyses of social inequalities in health, education may serve as a direct measure of cognitive function; knowledge may be a flexible resource possible to deploy in different contexts [51]. Education may further give access to other health-beneficial material and immaterial resources such as social networks and safe jobs with economic and personal rewards [52].

Results in this article indicate that educational attainment is a stronger predictor of technology use than income quartile group, possibly suggesting that resources affiliated with education is more closely related to technology use in this study context. The FCT suggest that social position and health outcomes are connected through time- and context-sensitive pathways [53]. The Norwegian health care system builds on universalistic principles; every citizen has the same formal rights to treatment. Could immaterial resources in this context lead to informal advantages? The size of your wallet may not directly affect the treatment you receive, but your knowledge, motivation, and networks may be of influence. If the use of technology is to serve as an intervening mechanism reproducing health inequalities in a Norwegian context, the immaterial resources connected to education may be the most relevant to study.

5.1. Limitations

These analyses have some limitations. The first ones concern the dependent variables. All three are indicators of technology utilization, asking about the use of blood pressure monitors. They do however differ in formulation: One asks whether respondents have a blood pressure monitor at home, implying ownership. Another question asks whether respondents ever have used specific measuring equipment, an ambulatory 24-h blood pressure monitor issued by a health care provider, where gatekeeping and access may differ from other measurement equipment. A third question asks whether respondents ever have measured their blood pressure themselves at home, not indicating ownership nor the use of a specific technology. Though the implications from these questions may be a source of error making comparisons across models difficult, I will argue that they all measure an underlying phenomenon, the inclination to health technology use. The discussion of results has also drawn few causal conclusions based on comparisons across models. Secondly, it is assumed that blood pressure monitors have undergone a diffusion process from 1997 to 2008, while there is no direct measure of this development. However, the assumption of diffusion is supported by research literature and descriptive statistics from the HUNT surveys. Lastly, there are unmeasured uncertainties related to the process of adopting and utilizing the blood pressure monitors. The involvement of the GP and the actual benefits from using a blood pressure monitor may vary between cases. This article is cautious in drawing conclusions about the direct health benefits of inequalities in technology use. More of interest is the demonstration of general patterns in a novel setting – which again can become the basis for later studies.

The income variable is based on that year's reported taxable income. Many respondents have a reported income of zero, which may include no actual income, or public or private benefits exempted from taxation. This group of respondents may therefore be heterogenous. Initial bivariate analyses indicated a high prevalence of low-educated, young, and old people in this group. Further, sensitivity analyses where zero-income respondents were excluded showed similar results as the analyses included in the article: The effects of income quartile groups on technology utilization were in the same 'direction', but at a lower level of statistical significance. It can therefore be argued that the zero-income group is relevant to include in these analyses.

There may be differing, unmeasurable needs for blood pressure monitors which possibly may affect results. Respondents answering the relevant questionnaire were selected based on symptoms of cardiovascular disease. In HUNT2, the selection variable was self-reported use of hypertension medication, while in HUNT3, respondents were selected to the module based on the results from a baseline medical screening. This could represent a potential bias; the different results at the two time points could also be influenced by the differing selection practices. However, previous research has demonstrated a low risk of patients over- and overreporting hypertension drugs in self-reported surveys (cf. [54]), which further could indicate that the dependent (and selection) variables are not systematically skewed by being self-reported rather than clinically measured.

In addition, systolic and diastolic blood pressure variables were added as controls. These two factors should adjust for some variation in need, but the professional autonomy and negotiations in the actual interaction between GP and patient may still influence the decision to prescribe blood pressure medication (relevant for HUNT2), and also for recommending the use of a blood pressure monitor. Previous research has shown social inequalities in the utilization of health care services, and that the degree of complexity in treatment regimens was associated with social inequalities in health outcomes, i.e. that well-educated patients benefitted disproportionally from complex treatments [22,55].

6. Conclusions

In this novel investigation of end-user technology in a universal health care setting, results suggest that the social gradient in use of blood pressure monitors was reduced as the technology was diffused from 1997 to 2008. This temporal trend is evident among several measures of technology utilization, but conclusions should be made with caution, as data was not perfectly comparable across survey waves. Education appears to be a more reliant predictor of technology use than income, which may suggest a relatively higher importance of immaterial resources in the Norwegian setting. The study adds contexts to the FCT, displaying how resources represented by educational attainment can have different effect on technology utilization depending on the innovation's diffusion status. These unequal effects may manifest themselves as inequalities in disease and mortality.

Innovative health technologies are in this context produced by private companies for the international market and given a monetary value based on supply and demand. Lupton [56] has described how a medical condition like blood pressure is surrounded by a network of actors, e.g. medical professionals, patients, and pharmaceutical and advertising companies, – all affecting the everyday use of technologies such as blood pressure medication and monitors. Technologies' monetary value may be of particular relevance in systems where health service utilization largely depends on the individual ability to pay. In the Norwegian universalist setting, the use of these technologies is predominantly independent of market logics but may nevertheless be subject to constraints based on budget control and efficiency. This article has demonstrated general patterns of social inequalities in technology use, but there are still uncertainties associated with the actual decision to adopt; I therefore support the request from Korda and colleagues [20] to investigate closer the intermediate role of medical professionals when health inequalities are reproduced through technology.

CRediT authorship contribution statement

Håvard T. Rydland: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing - original draft, Writing - review & editing.

Tables for appendix

Table A.1
Home-measure, full regression models (HUNT2)

	Model 1	Model 2	Model 3
Age	1.080 [0.995,1.171]	1.082 [0.998,1.174]	1.084 [0.999,1.177]
Age (squared)	0.999* [0.998,1.000]	0.999* [0.998,1.000]	0.999* [0.998,1.000]
Systolic blood pressure	1.007 [1.000,1.014]	1.008* [1.001,1.016]	1.008* [1.001,1.016]
Diastolic blood pressure	1.011 [0.999,1.024]	1.012 [1.000,1.024]	1.012 [0.999,1.024]
Gender (man)	1.912*** [1.495,2.445]	1.892*** [1.490,2.403]	1.853*** [1.447,2.373]
Income quartile group 2	1.047 [0.693,1.582]		0.969 [0.640,1.468]
Income quartile group 3	1.072 [0.722,1.592]		0.942 [0.632,1.405]
Income quartile group 4	1.479 [0.993,2.202]		1.085 [0.719,1.638]
Secondary education		1.625*** [1.247,2.118]	1.622*** [1.242,2.119]
Tertiary education		3.113*** [2.198,4.410]	3.034*** [2.115,4.354]
Pseudo-R	0.0437	0.0575	0.0577
N	6933	6910	6910

Odds ratios; 95% confidence intervals in brackets.
*p < 0.05, **p < 0.01, ***p < 0.001.

Table A.2
Auto-measure, full regression models (HUNT3)

	Model 1	Model 2	Model 3
Age	1.177***[1.141,1.214]	1.175***[1.140,1.212]	1.175***[1.139,1.213]
Age (squared)	0.999***[0.998,0.999]	0.999***[0.998,0.999]	0.999***[0.998,0.999]
Systolic blood pressure	1.011***[1.008,1.014]	1.011***[1.008,1.014]	1.011***[1.008,1.014]
Diastolic blood pressure	1.014***[1.008,1.019]	1.013***[1.008,1.019]	1.013***[1.008,1.018]
Gender (man)	0.772***[0.705,0.846]	0.780***[0.713,0.853]	0.773***[0.705,0.847]
Income quartile group 2	1.043 [0.882,1.234]		1.042 [0.881,1.233]
Income quartile group 3	1.063 [0.936,1.208]		1.060 [0.932,1.205]
Income quartile group 4	1.113 [0.956,1.297]		1.093 [0.934,1.279]
Secondary education		1.070 [0.967,1.183]	1.063 [0.961,1.176]
Tertiary education		1.108 [0.969,1.267]	1.090 [0.950,1.251]
Pseudo-R^2	0.0374	0.0375	0.0376
N	11,174	11,133	11,133

Odds ratios; 95% confidence intervals in brackets.
*p < 0.05, **p < 0.01, ***p < 0.001.

Table A.3
Self-measure, full regression models (HUNT2+3)

	Model 1	Model 2	Model 3	Model 4	Model 5
Age	1.060***[1.032,1.089]	1.069***[1.040,1.098]	1.064***[1.035,1.093]	1.066***[1.038,1.096]	1.068*** [1.039,1.097]
Age (squared)	0.999***[0.999,1.000]	0.999*** [0.999,0.999]	0.999***[0.999,1.000]	0.999***[0.999,1.000]	0.999***[0.999,1.000]
Systolic blood pressure	1.008***[1.005,1.011]	1.009***[1.006,1.012]	1.009*** [1.006,1.012]	1.009***[1.006,1.012]	1.010***[1.007,1.012]
Diastolic blood pressure	1.009***[1.004,1.014]	1.009***[1.004,1.014]	1.008**[1.003,1.013]	1.008***[1.004,1.013]	1.008***[1.003,1.013]
Gender (man)	1.036 [0.942,1.140]	1.084 [0.988,1.189]	1.035 [0.941,1.139]	1.023 [0.929,1.126]	1.018 [0.925,1.120]
Income quartile group 2	1.248**[1.059,1.471]		1.203*[1.020,1.420]	1.195*[1.013,1.411]	1.335 [0.998,1.786]
Income quartile group 3	1.234**[1.078,1.412]		1.182*[1.031,1.355]	1.171*[1.022,1.342]	1.807***[1.433,2.278]
Income quartile group 4	1.666***[1.428,1.944]		1.430***[1.220,1.676]	1.418***[1.211,1.662]	2.664***[2.098,3.383]
Secondary education		1.309***[1.174,1.459]	1.277***[1.145,1.425]	1.840***[1.530,2.213]	1.247*** [1.118,1.391]
Tertiary education		1.956***[1.703,2.247]	1.816***[1.572,2.097]	3.575***[2.773,4.610]	1.798*** [1.559,2.074]
HUNT wave 3	2.463***[2.221,2.732]	2.375***[2.140,2.636]	2.330***[2.097,2.589]	3.615***[3.036,4.305]	3.316*** [2.841,3.871]
Income quartile 2 * HUNT wave 3				0.877 [0.625,1.230]	
Income quartile 3 * HUNT wave 3				0.565***[0.444,0.719]	
Income quartile 4 * HUNT wave 3				0.428***[0.337,0.542]	
Secondary edu. * HUNT wave 3					0.579*** [0.471,0.711]
Tertiary edu. * HUNT wave 3					0.395*** [0.300,0.519]
Pseudo-R^2	0.0502	0.0538	0.0553	0.0583	0.0589
N	18,217	18,153	18,153	18,153	18,153

Odds ratios; 95% confidence intervals in brackets.
*p < 0.05, **p < 0.01, ***p < 0.001.

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