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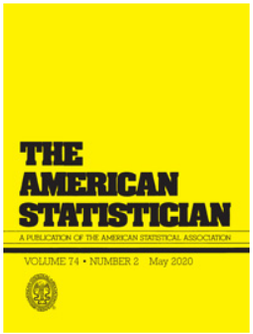

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HISTORY CORNER

How Does a Statistician Raise an Army? The Time When John W. Tukey, a Team of Luminaries, and a Statistics Graduate Student Repaired the Vietnam Selective Service Lotteries

Tim Johnson[a], Christopher T. Dawes[b], and Dalton Conley[c]

[a]Atkinson Graduate School of Management and Center for Governance and Public Policy Research, Willamette University, Salem, OR, USA; [b]Wilf Family Department of Politics, New York University, New York, NY, USA; [c]Department of Sociology and Office of Population Research, Princeton University, Princeton, NJ, USA

ABSTRACT
Scholars have documented the failed randomization in 1969's inaugural Vietnam Selective Service Lottery, but the story of how statisticians fixed that problem remains untold. Here, as the 50th anniversary of these events approaches, we recount how John W. Tukey, a team of statistical luminaries, and a graduate student from the University of Chicago repaired the draft lottery.

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Conscription; History of statistics; Physical randomization; Public policy; Randomization

1. Introduction

Fifty years ago, the inaugural draw of the Vietnam Selective Service Lotteries (VSSL) sought to allocate military service via a random process in order to purge the corruption and bias that mired previous methods of conscripting men for the U.S. conflict in Vietnam (Flynn 1993). However, in its first year, the VSSL's randomizing process failed (Fienberg 1971). Statisticians, at the time, quickly drew attention to this problem (Rosenbaum 1970a) and, in the years since, they have used the 1969 lottery's faulty randomization procedures as a teaching example (Starr 1997; Tijms 2012, pp. 55–56). Yet, despite the attention paid to these failings, scholars have made only brief asides about how statisticians repaired the draft (Mosteller, Feinberg, and Rourke 1983/2013, pp. 183–184). Here, we recount how John W. Tukey, a team of statisticians, and an enterprising graduate student proposed alternative randomizing procedures that the Selective Service System (SSS) ultimately adopted, thus restoring confidence in the lottery as an unbiased method of conscription.

2. Failed Randomization in the 1969 Vietnam Selective Service Lottery

The story of how Tukey and colleagues fixed the draft begins with the failure of the inaugural draft lottery on December 1, 1969. The 1969 lottery aimed to correct biases in the conscription of young males for service in the U.S.–Vietnam conflict. In the pre-lottery system, young males reported to their local draft boards upon reaching age 18, then those boards had wide latitude to call men for service or to warrant deferments—a practice that led to gross inequities (Baskir and Strauss 1978, pp. 6–10). High school graduates, the poor, and individuals identifying as black experienced higher rates of conscription (Shields 1981), as did men living in urban population centers, the Northeast, mid-Atlantic, Rockies, and Pacific Coast regions (Flynn 1993, p. 230).

Recognizing these biases, Richard Nixon advocated for a fairer method of conscription during the 1968 presidential campaign and charged members of his staff to design this method once he assumed office (Flynn 1993, p. 225). Staff heading the initiative recommended a draft lottery similar to those the United States had used, at times, to select individuals for military service in World Wars I and II (Flynn 1993, p. 246). These previous lotteries assigned men arbitrary serial numbers, placed those serial numbers in capsules, and, then, drew the capsules from a large glass bowl (Fienberg 1971). In the 1969 lottery, the SSS used men's birthdates to assign lottery numbers.[1]

The SSS listed each date of the year on a small piece of paper, slid the papers into plastic capsules, poured the capsules into a glass bowl, and drew them one by one on live TV (Selective Service System 2019). After pulling a capsule and announcing its date, officials linked the date to a three-digit "Random Sequence Number" (RSN), which ranged from 001 for the first date drawn to 366 for the final date drawn. The RSN associated with the month and day on which a draft-eligible man was born became his "lottery number." In 1970, the SSS scheduled men for military induction by calling RSNs in ascending sequence, starting with 001 and stopping when the RSN equaled the "Administrative Processing Number"—a

[1]Many articles recount the lottery procedures, thus we echo Johnson et al. (2018, p. 361, fn.6) and note that our description repeats conventional accounts (e.g., Johnson and Dawes 2016, p. 797; Erickson and Stoker 2011, p. 222).

CONTACT Tim Johnson tjohnson@willamette.edu Willamette University, 900 State Street, Salem, OR 97301, USA.

Figure 1. Selective Service Director Lt. General Lewis Blaine Hershey (left), Congressman Alexander Pirnie (middle), and Deputy Director Col. Daniel O. Omer (right) executing the first draw of the 1969 lottery. Selective Service Headquarters, 1969/MST. Trikosko, Marion S., photographer. Library of Congress: *https://www.loc.gov/item/2011661227/*.

number chosen to ensure adequate military staffing for the year. Because RSNs resulted from an arbitrary draw, they held the promise of assigning military service more fairly (Figure 1).

However, within weeks, this promise vanished. "The new draft lottery," David E. Rosenbaum reported in *The New York Times* on January 4, 1970, "is being challenged by statisticians and politicians on the ground that the selection process did not produce a truly random result." Arranging the average RSN values by month revealed a downward trend—201.2, 203.0, 225.8, 203.7, 208.0, 195.7, 181.5, 173.5, 157.3, 182.5, 148.7, 121.5 (Fienberg 1971, p. 260)—and this pattern raised concerns when viewed in light of the procedures used prior to the televised draw (Rosenbaum 1970a; Fienberg 1971). Prior to the draw, as described in Rosenbaum (1970a) and Fienberg (1971), two SSS officials enclosed dates within capsules, carrying out the process by month, beginning with dates in January. After capsules containing the birthdates of a given month were filled, they were placed in a box containing a cardboard divider. The officials put the newest batch of capsules on one side of the divider, so as to double check their count, and, then, pulled the divider, using it to press the new capsules into the previously deposited ones. They subsequently stirred the new capsules with those already placed in the box. This method necessarily resulted in each subsequent month being stirred one less time than the prior month and left December's capsules to be stirred only once. Furthermore, the box containing the capsules was poured into the glass bowl such that all capsules exited from one side; as Rosenbaum (1970a) recounted, officials did not know whether the side was adjacent to the well-mixed capsules with dates from earlier in the year or next to the poorly mixed capsules with dates from later in the year. Whatever the case, capsules with dates from later in the year likely rested in a stratum, either high or low in the bowl, and they stayed in that orientation because the capsules were not stirred again (Rosenbaum 1970a). Thus, consistently shallow or deep draws would pull those later dates with disproportionate frequency.[2] "Obviously," SSS Director Curtis W. Tarr concluded years later, "this process established greater vulnerability for those whose birth dates fell in the latter half of the year" (1981, p. 46). The goal of randomly assigning military service via the 1969 draft lottery had failed.

3. Repairing the Draft Lottery

The White House, it turns out, knew about the failed randomization in the 1969 lottery shortly after the draw took place and it set in motion efforts to correct the problem. On December 13th, Laurence E. Lynn, Jr., sent a candid memo to Henry Kissinger explaining that "the lottery drew first the birthdates from those months late in the calendar which had been put into the jar last" (Lynn 1969, p. 2). Kissinger transferred this information verbatim to Nixon in a memo on December 26th (Kissinger 1969). Three days thereafter, White House Staff Assistant John R. Brown III wrote to Nixon's prominent advisor, Peter M. Flannigan, to emphasize that Nixon "was disturbed

[2]Rosenbaum (1970a), writing a month after the first lottery draw, noted that "the persons who drew the capsules last month generally picked ones from the top, although once in a while they would reach their hand to the middle or the bottom of the bowl" (p. 66). This description dovetails with a salient detail in the news account of the first lottery draw; in that account, Rosenbaum (1969) explains that members of the Selective Service's Youth Advisory Committee pulled the capsules following Alexander Pirnie's first draw and each member selected "seven or eight capsules quickly and efficiently" (p. 20). Such rapid draws would seem to defy the possibility of deep digs into the bowl. Thus, the poorly mixed dates from later in the year likely rested at the top of the urn, though definitive evidence is not available.

by the attached memorandum from Dr Kissinger concerning draft lottery problems" and "it is very important that these deficiencies be cleared up" (Brown 1969).[3]

The challenge of addressing the deficiencies fell on Curtis W. Tarr (1981, 46)—who had just taken the helm of the SSS from its longstanding director, General Lewis B. Hershey. Tarr intended "[t]o design a lottery that would insure random selection" (1981, p. 46) and assigned one of his top officers, Greg Nelson, the task of touring universities to poll statisticians on how to execute the lottery (Tarr 1981, p. 46). On this tour, Nelson arrived at Princeton University where he encountered a scholar already contemplating the problem. "Most helpful among those Greg visited," Tarr later remembered (1981, p. 46), "was Professor John W. Tukey of Princeton, the chairman of a committee of statisticians concerned about randomness in the draft lottery."

Tukey had begun to work on the problem of inadequate randomization in the draft lottery after receiving a letter from Philip Handler, then-President of the National Academy of Sciences (NAS). In the letter, Handler asked Tukey to look over correspondence he had received from Senator Edward Kennedy, who chaired the Senate Subcommittee on the National Science Foundation at the time (Handler 1970a). Kennedy had written to Handler 17 days after the 1969 lottery to express concerns about analyses of the lottery draw. "The conclusions of these analyses," Kennedy worried, "are strikingly similar—that the selection sequence does not appear random, but instead operates to favor those born in the early months of the year" (Kennedy 1969, p. 1). Along with his concerns, Senator Kennedy posed a series of questions about the consequences of the inadequate randomization and the prospects of fixing these problems. Was it possible to discern whether the first draw "was in fact a random selection as required by law" (Kennedy 1969, p. 2)? Did "the lotteries in World War I and World War II exhibit a higher or lower probability of randomness than the December 1, 1969 sequence" (Kennedy 1969, p. 2)? And, most importantly, Kennedy asked "what new procedures would be recommended to produce a truly random selection in future draws" (1969, p. 2)?

Handler passed these questions to Tukey, explaining that Kennedy anticipated to hear the questions answered at a committee hearing in the late winter of 1970 (Handler 1970a). Recognizing the political sensitivity of the task, Handler offered to join Tukey at the hearings and delicately advised him that "[a]lthough I recognize that John Tukey requires no assistance whatever in this enterprise, it would probably increase our credibility if your statement could indicate the names of a few other reputable statisticians who would associate themselves with your statement" (Handler 1970a, p. 1).

Handler's acknowledgment "that John Tukey requires no assistance whatever in this enterprise" was not flattery. Tukey earned his bachelor's and master's degrees at Brown University within a four-year span ending in 1937, then initiated his PhD studies at Princeton where he earned his doctorate two years later and assumed a professorship that lasted until 1985 (Anscombe 2003, 290–291). During those years, Tukey's intellectual contributions linked his surname to various statistical tests and ideas—Tukey's range test, Tukey's test of additivity, Tukey's lambda distribution, Tukey's lemma, the Cooley-Tukey FFT algorithm—and they generated tools such as the box plot and jackknife estimation (Brillinger 2002). These contributions earned Tukey recognition in his day, including the National Medal of Science in 1973 and the IEEE Medal of Honor in 1982 (Anscombe 2003, p. 307).

Still, Tukey heeded Handler's advice and recruited a group of statisticians to discuss reforming the draft's randomization procedures (Tukey 1970a). The group's membership consisted of four former presidents of the American Statistical Association—William G. Cochran, Morris H. Hansen, Frederick Mosteller, and Frederick F. Stephan—and one fellow of the ASA—G.S. Watson (Tukey 1970b; see also Mosteller, Feinberg, and Rourke 1983/2013, pp. 183–184). Moreover, reminiscent of his practice of placing the by-line "____ and J.W. Tukey" on his solo works as a way to solicit collaboration (Anscombe 2003, p. 304), Tukey engaged his committee of doyens with a preliminary version of his testimony (Tukey 1970b), which they supported, albeit with minor editorial suggestions (Mosteller 1970a, 1970b; Stephan 1970; Watson 1970).

Tukey, in turn, produced a second draft of the testimony, which offers the best-available insight into the repairs that Tukey and his team recommended (the preliminary testimony, unfortunately, appears lost to time: unlike the second draft, it does not reside with Tukey's collected papers concerning the VSSL). Starting with a preamble that articulated the criteria to be fulfilled with a revised lottery, the second draft of the testimony proceeded to lay the intellectual fundamentals needed to understand the proposal. "Randomness does not lie in the appearance of a single result," the statement advised (Tukey 1970c, p. 2). "Rather, it lies in our understanding and knowledge about the relative probabilities of the possible outcomes—this comes only from knowledge and understanding of the process" (Tukey 1970c, p. 2). Focusing on the process of randomization, Tukey's testimony moved to an example of coin tossing, noting that it is not possible to discern whether a lone coin toss was random from its outcome. Instead, to judge the coin's suitability for randomizing, the coin's properties (weight, size, and so on), plus its frequency of producing different outcomes, must be known. Yet, as the testimony explained, such observations might not be possible in applications such as the draft. "In the case of a drawing to do something as complex as arranging dates in a supposedly random order," Tukey cautioned, "we often wonder whether the results support the hypothesis that the drawing process was statistically random or the hypothesis that the mixing is incomplete" (Tukey 1970c, pp. 2–3). Given that any single instance of randomization cannot adjudicate between those hypotheses, the planned testimony recommended procedures resilient to bias.

The most-resilient procedures, Tukey's testimony suggested, involved multiple randomizing devices (Tukey 1970c, p. 3). To illustrate this, Tukey continued with the example of coin tossing. "If two parties wish to have a nearly fair 'toss of a coin' what can they do?" the testimony puzzled (Tukey 1970c, p. 3). "The simplest thing is for each to toss a coin and let the result rest

[3]Professor James Hanley insightfully pointed us to the memos that we cite in this paragraph and he generously shared copies of them with us—a gesture of assistance for which we are very grateful.

on whether the coins match" (Tukey 1970c, p. 3). Consider a situation, the testimony asked, in which one party holds a standard coin with heads and tails, while "the other party is tossing a two-headed penny" (Tukey 1970c, p. 3). For sure, your partner in the randomization will throw heads, but there is a fifty-fifty chance you do too, assuming a fair coin, thus lowering what would be a certain outcome from your partner's throw to a 1 in 2 chance after your randomizing device is introduced. Introducing additional randomizing devices fractionalizes the bias of a lone instrument, thus the statement recommended such an approach in the draft lottery.

Ultimately, according to the testimony, the most credible such randomizing device was a table of random numbers. This position was one Tukey had staked out in his 1955 review of the RAND Corporation's *A Million Random Digits with 100,000 Normal Deviates*. In the review, Tukey (1955, p. 569) argued that a table of random numbers such as the RAND Corporation's "is almost certain to work out better than any scheme of flipping coins, throwing dice, or shuffling cards, and to be far, far better than any device not using mechanical randomization."

For one, Tukey (1955, p. 569) explained, coins, dice, and cards are laborious and time consuming, thus they "are mainly used for very, very small jobs." Second, tables of random numbers can facilitate the bias dilution Tukey advocated for in his team's testimony. For instance, to avoid the prospect of a party strategically using a random number table to bias an outcome in its favor, Tukey recommended procedures in which multiple parties state a number of their choosing and sum those numbers to determine the page at which to begin collecting values from the random number table (1955, p. 569). Finally, a random number table could face various tests to examine if it had attributes that one would expect from a random process; not proof of validity, but empirical data to raise confidence (1955, pp. 570–571). For these reasons, Tukey believed in 1955 and echoed in his planned testimony 15 years later that the best device for randomizing would be a table of random numbers.

Yet, Tukey also recognized that controversy surrounded random number tables. In a correspondence to Tukey and the team of luminaries dated eight days after Tukey had written the second draft of his testimony, Frederick Stephan (1970) raised concerns about the validation of random number tables. Tukey's testimony anticipated such criticism and mentioned that scrutiny of random number tables had led to their widespread adoption (Tukey 1970c, p. 5). Still, Tukey recognized that the political optics of random number tables would not be good: "there remains a place for drawings from a bowl as at least part of a public random lottery" (Tukey 1970c, p. 5).

But how does one draw from a bowl in a manner that would implement the reasoning developed earlier in his testimony? "While statisticians have been unsuccessful in making drawings from a bowl sufficiently random for their most delicate and refined purposes," Tukey (1970c, pp. 5 and 6) acknowledged, "they have learned quite a bit about useful precautions in using bowl-drawing." Restating ideas that Frederick Mosteller (1970a) had shared in a letter that arrived concurrently with the writing of the second draft of his testimony, Tukey (1970c, p. 6) emphasized "making the objects to be stirred as similar in size, weight, smoothness, and appearance as possible." Also, Tukey recommended testing the method of stirring the objects to be drawn so that the mixing procedure worked as advertised; to perform this test, he proposed using black and white capsules in a test draw so that one could visually examine the mixing process and determine its adequacy (Tukey 1970c, p. 6). Furthermore, sharing methods that Mosteller claimed to "have seen in news reels" (1970a, p. 2), Tukey advised continuous turning of the vessels holding the capsules to ensure thorough mixing throughout the draw (Tukey 1970c, p. 6). Following that same principle, Tukey also suggested placing objects in a pre-mixed order into the vessel from which they are drawn (Tukey 1970c, p. 6). The recommendations were pragmatic and easy to implement, despite having been overlooked in the first lottery.

Synthesizing these insights, Tukey's testimony proposed a process of implementing the lottery that differed markedly from the sequence of events that took place on December 1, 1969. The testimony culminated in the endorsement of a two-stage procedure in which dates of the calendar year would be paired with a set of arbitrary numbers—Tukey chose the numbers 501 to 866—via a randomized process and, then, a second random process would link the arbitrary numbers to the numbers 1 to 366, thus creating the ascending call of induction (Tukey 1970c, pp. 7–8). For instance, as Tukey (1970c, p. 7) explained, "if 16 June goes with 864 in the first matching while 864 goes with 137 in the second, the combination assigns 16 June to 137." The procedure diluted bias that might plague a lone drawing. Moreover, further confidence in the procedure could be gained via measures to ensure the draws' independence. "The combination of two very careful bowl-drawings, perhaps carried out simultaneously in widely separated cities, would be much more random and much fairer than the results of any one bowl-drawing," Tukey (1970c, p. 7) surmised. The testimony, furthermore, proposed the use of different methods for the pairing of arbitrary numbers with dates and the pairing of arbitrary numbers with the 1–366 sequence—say, a draw from a glass bowl in one and a pairing based on a table of random numbers in the other. "By combining matchings in this way," Tukey's testimony reckoned, "both the general public and professional critics would be able to see that justice indeed was being done" (Tukey 1970c, p. 8).

After putting forward these recommended procedures, the testimony concluded with a recap of its main points (Tukey 1970c, pp. 9–10). It reminded the audience that the quality of randomization results from the validity of the processes used, not the outcomes those processes produce, and it described a process that exhibited such validity. The planned testimony, in sum, contained the information that Senator Kennedy wanted to see presented.

That presentation, however, never seemed to occur. "I regret the fact that the hearing date has been postponed again and hope that you will not lose heart or interest," NAS President Handler wrote to Tukey roughly two weeks after the testimony's second draft had been composed (Handler 1970b). Search of the Senate's archive of hearings returns no evidence of John W. Tukey delivering testimony on the draft lottery. Yet, even though Tukey never seems to have delivered the testimony, the proposal at the core of the planned testimony appeared to survive in the practices of the SSS.

Upon arriving in Princeton, Greg Nelson found in Tukey a collaborator who had carefully considered ways to improve the draft and his boss, Curtis Tarr, was receptive to Tukey's ideas. "I must confess," Tarr (1981, p. 46) admitted in his memoirs, "that I never would have thought of considerations that [Tukey] judged quite important to the outcome of an appropriate drawing." Tarr's ultimate method for the lottery echoed ideas in Tukey's testimony:

> The plan that finally evolved called for 25 random tables of numbers 1 through 365 and 25 random tables of dates for each day in the year; these we requested from the National Bureau of Standards. From each of these sets, someone selected an envelope containing dates and another containing numbers. The tables provided the random means of depositing capsules containing numbers into one lucite cylinder and dates into the other. Baffles in these cylinders mixed the capsules while the cylinders rotated. Professor Tukey admitted that little was known about the physical dynamics of mixing, but he suggested the design of these cylinders and advised us to fill them with equal numbers of black and white capsules; this would help determine how long we should rotate the cylinders to assure mixing. Doing this, we decided to turn the cylinders for an hour before the drawing began and for several turns between each selection. (Tarr 1981, p. 46)

Tarr's description reads as if it were plagiarized from Tukey's testimony and the suggestions his brain trust had offered. In Tarr's description of the lottery's methods are tables of random numbers, two independent draws, test runs with black and white capsules, and the continuous turning of cylinders just like Mosteller had seen in news reels. News articles published prior to and after the 1970 lottery draw corroborate Tarr's account (Rosenbaum 1970b, 1970c), as did a report published in *Science* by Joan R. Rosenblatt and James J. Filliben (1971), which provided further details of how the NBS selected, via its own random process, the random number tables to be used in the ordering of capsules (Figure 2).

The only feature of Tukey's testimony that remained conspicuously absent was the suggestion to match arbitrary numbers to dates and, then, separately, to match arbitrary numbers to the numbers to be used in the call for induction. In its place was simply a matching of dates to numbers, with the added provision of using random number tables to order the placement of capsules into the cylinders. Where did such a procedure originate? Although Tukey's planned testimony mentions that items drawn in a lottery ought to be placed in the selection vessel "in a prechosen, well-shuffled order" (Tukey 1970c, p. 6), it proceeds to advocate for "even more precaution" (p. 6) and a complex procedure that the final lottery did not use. What motivated the simpler procedures? Tukey's collected papers, housed in the American Philosophical Society's library in Philadelphia, offer a clue.

In the same file as Tukey's planned testimony and its associated materials resides a letter from Paul Meier of the Department of Statistics at the University of Chicago. Enclosed with Meier's correspondence is a letter that one of his students, Jonathan W. Still, sent to the SSS headquarters (Still 1970a), as well as a

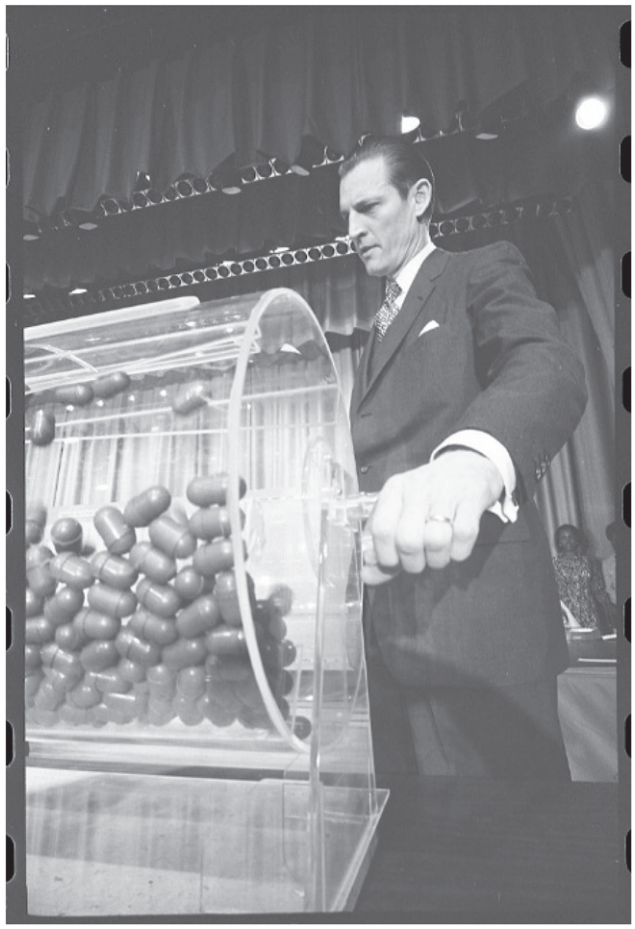

Figure 2. Curtis W. Tarr, 1972, Commerce Department Auditorium, Washington, DC/TOH. O'Halloran, Thomas J., photographer. Library of Congress: *https://www.loc.gov/item/2015645171/*.

letter Still wrote to Meier, a newspaper clipping, and a lengthier, unsent version of Still's letter to the SSS (Still 1970b). "I forward this correspondence to you," Meier (1970, p. 1) explained to Tukey, "on the presumption that you will almost surely be one of the persons who has been or will be consulted on the draft lottery problem." In the letter sent to the SSS, Still offered a plan that explicitly sought to reconcile the technical precision of employing a random number table with the transparency of a public draw. "I would propose the following," Still (1970a, p. 1) humbly submitted:

> Arrange the 366 date slips in calendar order. Then, from one of the published tables, obtain random numbers between 1 and 366. As the number corresponding to each date is selected, put that date slip into a capsule and put the capsule into a box, for later transfer to a glass bowl, or directly in to the glass bowl. Then proceed with a public drawing as was done last December 1. (Still 1970a, p. 1)

The SSS responded to Still with a generic letter from a Colonel writing on behalf of Director Tarr (Jensen 1970). Yet, even though the Colonel brushed it off, the letter clearly stuck with Tukey. Tukey housed it with his papers on the draft lottery and wrote back to Still's professor, Paul Meier, with an understated nod to his student's suggestion (Tukey 1970d):

Dear Paul:
Thank you for the correspondence about the draft lottery. As you will have seen by the newspapers, the date of July 1 has been announced, and it has been announced that Curtis Tarr has decided to use capsules put in the bowl in accordance with a randomized order. Tarr seems to be a very nice chap with a real interest in doing things right. I think we may reasonably have strong anticipations that this lottery will be very, very much better done than the last one.
With best regards,
John W. Tukey

Tukey did not state directly that Still's proposed method was adopted, but the final procedures for the 1970 lottery draw enlisted random number tables to order capsules as Still suggested. That is, the lottery ultimately implemented Tukey's "prechosen, well-shuffled order" via the details of Still's recommendation, not those advanced in Tukey's testimony. Thus, though Tukey "required no assistance in the enterprise," as Philip Handler initially put it, he had received it nonetheless. With the help of some of the greatest statistical minds of all time and quite possibly with that of an innovative grad student, Tukey had proposed a more-valid randomizing procedure for the draft lottery.

Conclusion

Past research has focused on statisticians' role in identifying failures in the randomization procedures used in the 1969 VSSL. This article has shed light on the lesser-known story of how statisticians led by John W. Tukey corrected those failings and repaired the draft lotteries. As the 50th anniversary of those events approaches, the statisticians who figured prominently in them deserve recognition and the field of statistics deserves the opportunity to reflect upon the important public service its members performed.

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